

Chapter 8

Economic and Social Significance of Information Technologies

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Highlights

IT AND THE ECONOMY

- ◆ **The use of information technologies (IT) is pervasive in the United States.** The real net computing capital stock in the private sector was \$155.8 billion in 1995. And, in many industries, the number of employees who use a computer at work is more than 50 percent; in the banking industry, it is 85 percent.
- ◆ **IT is believed to have contributed to the country's structural shift to a service economy.** In the United States, growth in services as a proportion of gross domestic product has been led exclusively by IT and knowledge-intensive industries such as finance, insurance, real estate, and professional services.
- ◆ **The U.S. Bureau of Labor Statistics projects employment in IT-producing industries to nearly double from 1986 to 2006.** This expansion is due almost entirely to growth in computer and data processing services (including software manufacturing); employment declines are projected for the IT hardware industries. Since precise projections are always difficult, this should be taken as a general direction, not an exact level of employment.
- ◆ **Several comprehensive studies, using a variety of data and methods, indicate that there is an overall skill upgrading taking place in the labor force,** a trend attributed to the greater use of IT in many occupations.
- ◆ **The incidence of IT-related injury and employee surveillance in the workplace are on the rise,** but impacts on individuals are uncertain.
- ◆ **Recent research suggests—unlike past evidence of a “productivity paradox”—that there may be measurable productivity gains from IT.** Nonetheless, it is difficult to predict the precise organizational and firm-level conditions that foster the effective use of IT.

IT AND EDUCATION

- ◆ **By 1992, 80 percent of all K-12 schools had 15 or more microcomputers for instruction. In 1996, 85 percent of all schools had access to multimedia computers, 65 percent had Internet access, and 19 percent had a satellite dish.** Internet linkages are not necessarily widely accessible within schools—in 1996, only 14 percent of instructional classrooms had an Internet hook-up.
- ◆ **In fifth grade, more than half (58 percent) of the instructional use of computers is for teaching academic subject matter.** By 11th grade, less than half (43 percent) of computer-based instruction is for content; 51 percent is for computer skills training.

- ◆ **Meta-analyses of educational studies conducted between the late 1960s and the late 1980s consistently reveal positive impacts of computer-based instruction at the K-12 level.** Estimates of the order of magnitude vary, but one meta-analysis of 40 studies gave evidence of learning advantages that ranged from the equivalent of one-third to one-half of a school year for K-6 education.
- ◆ **The cost effectiveness of computer-based instruction relative to other forms of instruction has not been demonstrated.** As pressures to increase IT spending grow, it is likely that school districts will face greater opportunity costs between IT and other education-related expenses.
- ◆ **There is significant educational inequity in access to computers and the Internet.** Schools whose student body is represented primarily by minority or economically disadvantaged students have one-third to three times less access to these technologies than do schools attended primarily by white or nondisadvantaged students.
- ◆ **Poor and minority students cannot compensate for less computer access at school in their homes.** In 1993, blacks and Hispanics had half as much ownership of home computers as whites. The poorest and least educated groups had about one-tenth the access to home computers as the most affluent and educated groups. Research indicates that when the “informationally disadvantaged” are given access to computers and the Internet, they use these resources effectively for self-empowerment.

IT AND PRIVATE CITIZENS

- ◆ **Concerns about information privacy are growing larger and stronger.** In a 1996 Equifax/Harris privacy survey, two-thirds of the respondents said that protecting consumer information privacy was very important to them.
- ◆ **The vast majority of Americans believe that companies should be prohibited from selling information about consumers—including their income, bill-paying history, and product purchases—and that stiff restrictions should be placed on access to medical records.** Unfortunately, most Americans also believe that they have already lost control of personal information about themselves.

Introduction

Chapter Overview

The revolution in information technologies (IT) has been likened to the industrial revolution in terms of its potential scope and impact on society (Alberts and Papp 1997; Castells 1996; Freeman, Soete, and Efendioglu 1995; and Kranzberg 1989). With the exception of electrification, no other modern advances in technology have had the capacity to affect so fundamentally the way people work, live, learn, play, communicate, and govern themselves. Indeed, some social philosophers expect that IT might affect the nature of what it means to be human—changing values, emotions, and cognitive processes.

Science & Engineering Indicators – 1998 attempts to benchmark certain dimensions of the growing role of information and information technologies in American society. At present, there is little systematic data on either the diffusion of IT or its impacts on society. Metrics are confounded by both the fuzziness of IT as a concept and the interactive effects of so many social variables—including age, ethnicity, income, learning processes, individual attitudes, organizational structures, and management styles. In addition, the rate of technological change since the early 1980s has often outpaced our ability to define what it is we want to know and what data ought to be collected.

As a consequence, this chapter focuses on three core areas where the analytical questions have stabilized and where there is a large body of existing research:

- ♦ the role of IT in the national economy;
- ♦ the influence of IT on K-12 student learning; and
- ♦ the impact of IT on citizens, particularly with respect to equity and privacy.

Each of these areas illustrates the ways in which science-based technology can have profound social consequences (both positive and negative) and the difficulties in defining, measuring, and tracking a technology that is still emerging.

Three generalizations can be made about the state of our empirical understanding of IT's effects on society. First, quantitative indicators of IT diffusion are relatively abundant but not necessarily regularly updated. Second, indicators of the actual effects of IT on individuals, institutions, and markets are extremely difficult to establish. Currently, statistical studies in many areas of interest are both nonrepetitive and noncumulative; that is, studies do not necessarily use the same methodologies (thus generating different statistics) and do not build on one another (findings from one study are not verified and expanded on in others). This state of affairs has less to do with the quality and rigor of the research than with the complexity and dynamism of IT as a subject of study. Moreover, experts have not determined how to measure some elements of considerable interest, such as productivity in some service industries.

Third, the state of existing research makes it difficult to draw any definitive conclusions about the impacts of IT on society. For example, evidence exists of both increased and

decreased productivity, as well as of both a lowering and an upgrading of skills in the labor force. Both positive and negative consequences may also be found. For example, computer-aided instruction may clearly enhance some forms of student learning, but extensive use of some computing environments may interfere with aspects of child development. Positive effects (such as enhanced business performance or student learning) are often highly contingent upon the presence of a number of other factors, such as appropriate organizational structures, managerial style, the adequacy of teacher training, and the attitudes of the individual using IT. All that may be said definitively about IT's social and economic impacts is "it depends": both on how we have measured and modeled the subject of study, and on the all-too-human conditions surrounding its use.

The evidence and indicators presented in this chapter do cohere as a somewhat sketchy image of the social and economic impacts of IT as of the mid-1990s. The predominant feature reflects the scope and presence of IT in the economy, schools, and the home. In many industries, the level of computer use (as measured by the number of employees with computers on their desktop) exceeds 50 percent. More than 70 percent of large firms in key manufacturing sectors (such as machinery, electronics, and transportation) use computer-aided design and/or numerically controlled machine tools. In addition, many services (such as automated banking, credit card sale authorization, express delivery, and electronic commerce) could not exist in the absence of an IT infrastructure.

Elementary and secondary schools have similarly high rates of IT adoption. By the early 1990s, 80 percent of all K-12 schools had 15 or more instructional computers, and the national median number of students per computer was 14—essentially one computer per classroom. Less pervasive is access to the Internet in schools; in 1996, only 14 percent of the instructional classrooms nationwide were linked to the Internet. At the household level, roughly one-quarter of all homes had a personal computer (PC) in the early 1990s; these households were disproportionately wealthy and white. As discussed in several sections of this chapter, IT is not necessarily ubiquitous, and schools and homes reflect a real inequality in access to computers and other information technologies.

The effects of IT are most clearly visible at the "micro" level—that is, the level of the individual firm, classroom, household, etc. For example, the strongest indicators of economic enhancements from IT are seen with firm-level data sets and for impacts that reflect improvements in firm-level activities (such as transaction processing time, product quality, cycle times, and customer service and convenience). The measurable learning effects of computer-based instruction (CBI) are most pronounced for the elementary grades and for rote learning; computer-enhanced higher order thinking skills are harder to demonstrate, perhaps because of a lack of appropriate software, but also because of the greater emphasis on building computer skills in secondary school rather than on content learning.

Chapter Organization

This chapter begins with a discussion of the nature of information technologies and the issues involved with measuring the effects of IT on society. Subsequent sections address (1) the role of IT in the economy, (2) the effects of IT on K-12 education, and (3) IT and the citizen. The final section addresses the need for better IT metrics.

Information Technologies

IT reflects the fusion of two key technological changes: the development of digital computing and the ability to transmit digital signals through telecommunications networks. The foundation of all information technologies and products is the ability to represent text, data, sound, and visual information digitally. By integrating computing and telecommunications equipment, IT offers the ability to access stored (or real-time) information and perform an extraordinary variety of information-related tasks.

IT does not represent a single technology as much as it does systems of interactive technologies used for information processing. There are literally hundreds of commercial products—ranging from telephones to supercomputers—that can interact in an information processing system. The distinctly different functions of many of these products contribute to a sense of fuzziness about IT's technological boundaries. Keen (1995) suggests, however, that IT can essentially be grouped into four basic technological elements of information processing:

- ◆ tools to access information,
- ◆ telecommunications linkages (including networks),
- ◆ information processing hardware and software, and
- ◆ storage media.

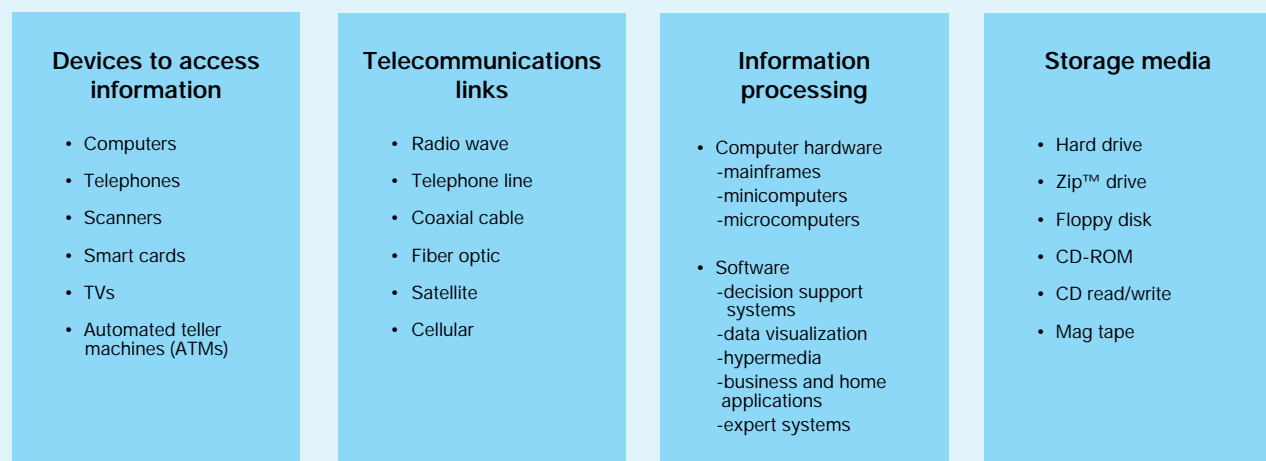
Figure 8-1 illustrates the more common technologies that are used for each of these elements and reinforces the understanding of IT as an interactive system of multipurpose technologies rather than a single class of products.

The rapid social and economic diffusion of IT since 1980 has been stimulated by threshold technical changes in computing power, applications, telecommunications, and networks as well as concurrent reductions in the cost of technology. Text table 8-1 illustrates advances in computing power (measured as million instructions per second) that have occurred since the introduction of the first microprocessor, while text table 8-2 presents trends in the relative cost of this power for popular commercial microprocessors. Notably, the computer price deflator calculated by the U.S. Department of Commerce has declined more than fortyfold since 1977 (Warnke 1996).

The other key development in IT is the growing connectivity of computers and information—and, by logical extension, people. Computerized data exchange is the basis for automated teller machine (ATM) transactions, credit card authorizations, airline reservation systems, electronic commerce, and overnight delivery services. A more advanced system, electronic data interchange, is becoming a standard form of communication between suppliers and customers to streamline ordering, purchasing, distribution, and billing operations. The extent of this growing networking is evident in the diffusion indicators—one study estimates that the number of installed local area networks was just over 1 million in 1981, about 12 million in 1990, and close to 40 million in 1995 (Morrison and Schmid 1994).¹ Use of the World Wide Web, a subsystem on the Internet (see “History of the Internet”), exploded with the introduction of the Mosaic search engine

¹Local area networks are devices (computers, telephones, security systems, automated cash registers, etc.) connected into an information network, typically in a single building or very small geographic area.

Figure 8-1.
Technological components of an information processing system



Text table 8-1.
Trends in computing power

	Micro-processor	Transistors (thousands)	Million instructions per second	Word size (in bits)
1971	4,004	2.3	0.06	4
1974	8,080	6	0.64	8
1978	8,086	29	0.75	16
1982	80,286	134	2	16
1985	80,386	275	6	32
1989	80,486	1,200	20	32
1993	Pentium	3,100	100	32
1995	Pentium Pro	5,500	250	64

SOURCE: F. Moris, "Semiconductors: The Building Blocks of the Information Revolution," *Monthly Labor Review* (August 1996): 6-18.

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Text table 8-2.
Trends in computing price relative to speed

	Device	Million instructions per second	Price per million instructions per second (\$)
1975	IBM Mainframe	10	1,000,000
1976	Cray 1	160	125,000
1979	DEC VAX	1	200,000
1981	IBM PC	0.25	12,000
1984	Sun 2	1	10,000
1994	Intel Pentium Micro	66	3,000

SOURCE: J. Warnke, "Computer Manufacturing: Change and Competition," *Monthly Labor Review* (August 1996): 18-30.

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in 1993. Market experts estimate that the Web had 69 million users in 1997 and about 80,000 servers; by 1996, about half of all U.S. companies had sites on the Web (IDC 1997).

The Information Society

The development, diffusion, and consequences of IT are part of a larger context: that of the "information age" or "information society." What exactly these concepts mean is uncertain, as they are not consistently used or explained in scholarly and popular discussions of the emerging information revolution.² In an extensive review of writings about the information age, Webster (1997) concludes that it has five distinct analytical dimensions: technological, economic, occupational, spatial, and cultural.³ While not all analysts agree that human civilization is undergoing an information revolution, there is a pervasive sense that "information and com-

²For a thorough and up-to-date treatment of many of the issues surrounding the concept of the information society, see Alberts and Papp (1997).

³The cultural dimension includes education, governance, religion, values and ethics, and popular culture.

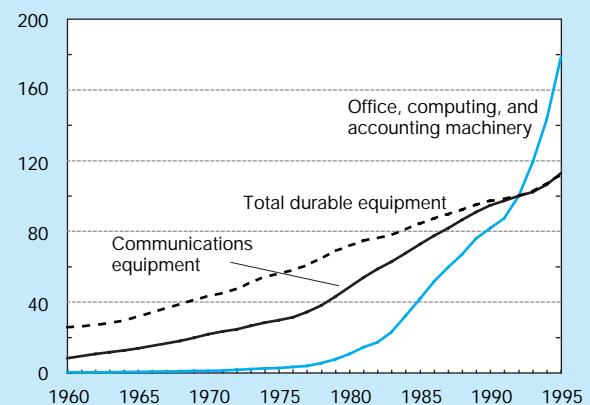
munications will become the dominant forces in defining and shaping human actions, interactions, activities, and institutions" (Alberts and Papp 1997, p. 1).

The present amount, variety, and accessibility of information within American society is unprecedented. Indicators of the economic and social diffusion of IT reveal that the technological capacity for information consumption has increased dramatically in the United States. The volume of IT is most substantial in the economic sector, where the real net computing capital stock was 200 times greater in 1995 than it was in 1975, and the real net communications equipment capital stock was five times greater than in 1975.⁴ (See figure 8-2.) In many industries, the number of workers who use a computer at their job now ranges from 50 to 85 percent (for more detail, see "Impacts of IT on the Economy"). In the manufacturing sector, U.S. Census data indicate that by the late 1980s, 83 percent of firms with 500 or more employees in the metals, machinery, electronics, transportation, and instrument industries used computer-aided design; 70 percent used numerically controlled machine tools (Berman, Bound, and Griliches 1994).

Extensive diffusion of IT is likewise found in the education sector. By 1985, more than three-quarters of all elementary and secondary schools had at least one microcomputer for student instruction. By 1992, all K-12 schools had at least one instructional microcomputer, and 80 percent had 15 or more computers. (See figure 8-5.) The median number of students per computer correspondingly declined from 42 in 1985, to 20 in 1989, to 14 in 1992—essentially the equivalent of one computer per

⁴In 1995, the total net capital stock of office, computing, and accounting machinery was \$155.8 billion; for communications equipment, it was \$388.5 billion (in current dollars). See U.S. BEA (1997), pp. 79-81.

Figure 8-2.
Real net stock of IT equipment in the private sector
(Chain-type index, 1992 = 100)



NOTES: Total durable equipment is nonresidential equipment. Chain indices are new constant value indices developed by the U.S. Bureau of Economic Analysis. IT is information technologies.

See appendix table 8-2. *Science & Engineering Indicators – 1998*

History of the Internet

For many Americans, nothing epitomizes IT as much as “the Net.” The Internet is a meta-network for a variety of subnetworks and applications such as the World Wide Web, bulletin boards, Usenet newsgroups, e-mail, scientific data exchange, and more.

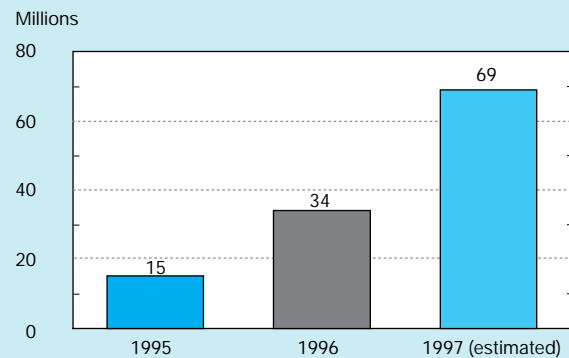
The foundation for the Internet was ARPANET, a network that started as four computer nodes in 1969. ARPANET was initiated by the U.S. Defense Advanced Research Projects Agency, and was based on a then-new telecommunications technology called “packet switching.” ARPANET flourished as a medium for information and data exchange among universities and research laboratories. Moreover, it stimulated the development of TCP/IP, a communications protocol distributed with the UNIX operating system which has now become the standard for the Internet and other types of commercial telecommunications. By the late 1970s, ARPANET represented hundreds of computer nodes and had integrated several separate computer networks, including one based on satellite technology.

The “real” Internet resulted directly from the National Science Foundation’s (NSF’s) sponsorship of CSNET, and later, NSFNET (a high-speed network funded by NSF to link its supercomputing centers). NSFNET replaced ARPANET in 1990 and expanded to include a variety of regional networks that linked universities into the backbone network. Large numbers of smaller networks quickly linked into NSFNET—albeit without any planning, control, management, or security. By early 1994, commercial networks became widespread; almost one-half of all registered users of the network were commercial entities. Additionally, the amount and variety of information carried by NSFNET escalated.

Two related events dramatically reshaped the character of the Internet. First, scientists at the European Center for Particle Research (CERN) developed the World Wide Web and introduced it in experimental form in 1989. Second, in 1993, a team of programmers at NSF’s National Center for Supercomputing Applications at the University of Illinois introduced Mosaic, a graphical (hypermedia) browser for exploring the Web. Because Mosaic was free and available to the public on the Internet, use of the Web (via Mosaic) soared. The number of Web users doubled annually from 1993 to 1996, and was estimated to be 69 million worldwide in 1997. (See figure 8-3.) Netscape, the leader in commercial Web browser software (accounting for 70 percent of the market), reported that in mid-1997, about 600,000 new users *per week* were accessing its software (NUA Ltd. 1997). And, compared to other countries, the United States has more Internet servers per capita than any other nation except Finland. (See figure 8-4.)

NSFNET was decommissioned in 1995, when there were enough commercial Internet service providers, Web browsers, and search engines to sustain the network’s operations and management; the Internet is now fully privatized. After

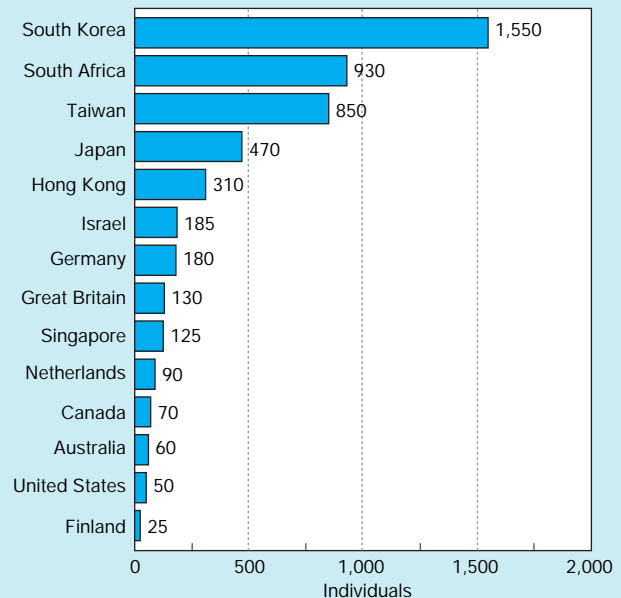
Figure 8-3.
Number of World Wide Web users



SOURCE: International Data Corporation, “New Priorities and Technologies for the Year Ahead,” <<http://www.idcresearch.com/BS97/111.htm>> (June 1997).

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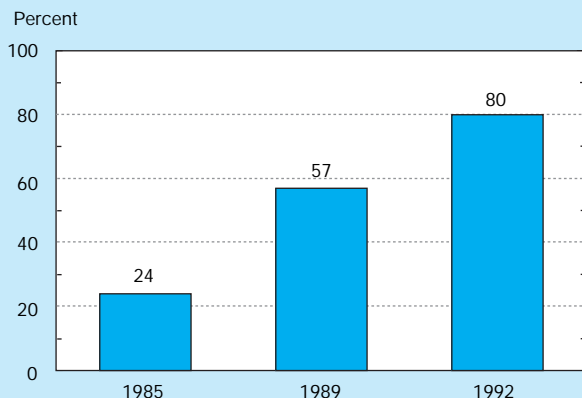
Figure 8-4.
Number of individuals per Internet server, for selected countries: 1996



SOURCE: M. Martin, “When Info Worlds Collide,” *Fortune* October 28, 1996: 130-33. Science & Engineering Indicators – 1998

transforming from ARPANET to NSFNET to the Internet, the next stage of evolution is the “information superhighway”—a telecommunications infrastructure that would allow *all* national public networks and education and research institutions to link with one another at higher speeds than today. Promoted first by the federal National Information Infrastructure Initiative, and now by the Next Generation Internet Initiative, the new information superhighway will be a higher speed, more functional telecommunications network. For more information on the Internet, see Keen (1995) and Cerf (1997).

Figure 8-5.
Percentage of elementary and secondary schools with 15 or more computers



SOURCE: U.S. Bureau of the Census, *Statistical Abstract of the United States 1996*, table 262 (Washington, DC: U.S. Government Printing Office, 1996); data based on the Computers in Education Study conducted by the International Association for the Evaluation of Educational Achievement.

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classroom.⁵ As addressed in the last section of this chapter, educational access to computers and other IT is not equitable in terms of race, ethnicity, or income.

Use of computers in the home lags behind the economic and education sectors. U.S. Bureau of the Census (1993) data indicate that although the number of homes with a computer nearly tripled from 1984 to 1993, this amounted to only 23 percent of all households by 1993. Household use is clearly linked to income and ethnicity. Nearly twice as many adult whites had a computer at home in 1993 as did blacks (27 versus 14 percent, respectively); and 62 percent of all households with incomes of \$75,000 or more had a computer—double the rate of households with incomes of \$35,000 to \$49,999 and well over triple the rate of lower income groups. (More detail on the significance of ethnicity and class is discussed later in “Equity Issues.”) The comparatively low level of access to home computers in the early 1990s may be changing quickly, however. Data discussed in chapter 7 indicate that 43 percent of adults in a 1997 survey have a computer at home. (See appendix table 7-26.) In addition, a number of PCs priced less than \$1,000 were commercially introduced in 1997, and 80 percent of PC shipments are now expected to be for the home market (Pargh 1997 and IDC 1997).

Determining the social and economic effects of this growing use of IT in society is complicated. First, the scope of such effects—both positive and negative—is immense. For example, over a decade ago, Michael Marien (1986) of the World Future Society compiled and categorized 125 expected

effects of IT, ranging from the individual to the international system. Second, many types of effects are hard to measure—such as productivity in the service sector or the psychological, emotional, and cognitive impacts of prolonged exposure to computing environments. As discussed in the next section, it is easier to measure and develop indicators for the diffusion and uses of IT in society than it is to isolate and examine the consequences of that use.

Issues in Measurement and Research

The measures and indicators used here are unlike those found in other chapters of this volume in several ways. First, data on IT are rarely collected on a systematic basis. Accordingly, there are no extensive time-series data on IT diffusion and its effects—the type of indicators available reflect ad hoc interests rather than ongoing analytical needs. (Two notable exceptions are the time-series data on IT investments and capital stock reported by the U.S. Bureau of Economic Analysis and the data on IT in schools collected by Quality Education Data, Inc.) Second, IT as a concept is not clearly defined, and available data are frequently not comparable. In contrast, such indicators as research and development (R&D) expenditures and scientists and engineers are both well-defined and clearly documented not only in the United States, but in the international community as well.

Third, some subjects of interest have not been quantified, such as labor productivity for several key IT industries, including computing and data services. Fourth, it is often extremely difficult to isolate the effects of IT from other factors, such as industrial deregulation; management practices; employee attitudes; and the myriad conditions affecting student learning and achievement: individual ability, teaching skill, classroom environment, nutrition, affinity for the subject matter, and so on. Fifth, there is a time factor. The effects of a technology on human behavior may take years to show up and often may be reliably detected only through controlled, longitudinal study of a set of individual subjects. Finally, much insight on the effects of IT comes from case studies—a useful form of analysis but one that cannot be used to generalize to a larger group or population.

When new areas of inquiry emerge in the social sciences (such as the social and economic impacts of IT), it can take years to develop a dominant “heuristic” (models, theories, and methods) with which to organize research and empirical findings. The field of study surrounding the social and economic impacts of IT is consequently characterized by the full spectrum of social science research methods and techniques. Research and analyses range from qualitative (the use of historical analysis, guided observation, case studies, pattern matching, metaphors, and other narrative information) to quantitative (controlled experiments, cross-sectional or longitudinal data collection and analysis, survey research, content analysis). In all instances, the objective is to determine patterns of regularities in human behavior and the causes of those patterns.

⁵See U.S. Bureau of the Census (1996), table 262. Data are based on the Computers in Education Study conducted by the International Association for the Evaluation of Educational Achievement.

Two “decision rules” were used when evaluating research for inclusion in this chapter:

- ♦ Diffusion indicators had to be obtained through valid and representative sampling methodologies. In some instances, data from leading market research companies were used, even though detailed information on sampling methods was not available; these firms (such as International Data Corporation) are considered reputable and reliable sources of IT market data.
- ♦ Empirical studies had to use valid statistical analysis and sampling methods (when appropriate), control for non-IT factors, and be representative of the group or sector under study. Qualitative studies had to follow an explicit research design and be consistent with other narrative and descriptive information.

Diffusion indicators are relatively abundant because they can be easily obtained through conventional survey methods, and there is considerable commercial interest in the demographics of the IT market. Economic effects have been widely studied, but empirical research frequently tends to result in contradictory findings. Quantitative research on the effects of IT on student achievement is extensive (bibliometric searches yield thousands of citations), but diverse research designs make it extremely difficult to cumulate findings. The educational findings discussed here are the results of “meta-analysis,” a technique used for integrating multiple studies (this technique is discussed more in the section on “IT, Education, and Knowledge Creation”). Judgments about the impact of IT on equity and privacy are largely inferred from descriptive data and qualitative analysis because of the difficulties in quantifying political power and levels of individual privacy.

Impacts of IT on the Economy

Diffusion of IT has had significant effects on business activity. Computer-integrated manufacturing, for example, enables automated model changes on the production line as well as fully integrated design and manufacture. Resulting shortened cycle times and the declining significance of economies of scale have led to a competitive environment that focuses on quality, customization, and timeliness of delivery. Firm-level IT networks (“intranets”) integrate finance, manufacturing, R&D, operations, and marketing, and have fostered the rise of strategic management in industry. The IT-based integration of producer-supplier and wholesaler-retailer networks enables responsiveness to daily changes in customer demand and a fundamental revolution in inventory management. Advanced telecommunications technologies have integrated international capital markets and literally created a global financial industry. In short, IT has moved economic markets and business behavior far closer to “real-time” mode than has ever existed in the past.

Yet in almost all instances, the precise economic impacts of these effects cannot be quantified, and there is often con-

tradictory evidence about the role of IT. For example, research (reviewed below) shows that IT has contributed to both deskilling and skill upgrading in the workplace, although the trend appears to be toward upgrading. Until very recently, the empirical record demonstrated that, in spite of the enthusiastic adoption of IT by business, IT has had little observable impact on productivity growth in the United States (a paradox explored further below).

This section summarizes quantitative indicators of the economic effects of IT in three core areas of interest:

- ♦ the structure of the economy,
- ♦ employment and workers, and
- ♦ the “productivity paradox.”

The findings indicate that IT has diffused unevenly throughout the economy and that the net impacts on employment and productivity are uncertain—at least as traditionally measured.

Economic Growth and the Service Economy

IT contributes to macroeconomic output in a variety of ways. For example, IT can create better ways of generating goods and services, improve production efficiencies, and increase both labor and multifactor productivity. Growth accounting⁶ studies confirm IT’s positive impact on total U.S. economic output; estimates of the total contribution of IT to the real U.S. growth rate range from 0.16 to 0.52 percent (Jorgenson and Stiroh 1995, Oliner and Sichel 1994, and Sichel 1997).

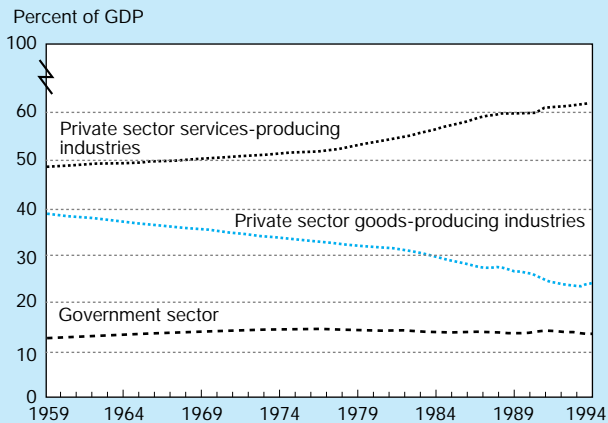
IT is commonly credited as being a key reason for the structural shift from manufacturing to services in the U.S. economy. Rapid growth in existing services, such as banking, and the creation of new industries, such as software engineering, are attributed to the widespread diffusion of IT in the service sector infrastructure (NRC 1994a, and Link and Scott 1998). From 1959 to 1994, the service sector grew from 49 to 62 percent of U.S. gross domestic product (GDP), while manufacturing declined from 28 to 17 percent.⁷ (See figure 8-6 and appendix table 8-3.) In the past three decades, growth in services has, on balance, exceeded growth in every other industrial sector—agriculture, mining, construction, and manufacturing.

The expansion of the service sector has been driven entirely by industries that are often classified as “knowledge” industries (see Machlup 1962)—finance, insurance, and real estate (FIRE)—as well as a number of professional services,

⁶Most output and productivity studies use what is known as a “production function” model. The resulting statistics are typically least-squares correlations and estimates based on a log-linear regression. Growth accounting, a technique developed by Denison (1985), principally uses an arithmetic/algebraic procedure on national income accounts data. Robert Solow received the Nobel Prize in economics for his estimates of the contribution of technical change to aggregate productivity using a production function model (Solow 1957). For more detail on these models, see NSB (1996), chapter 8.

⁷Note that these figures differ somewhat from those frequently published; this is because the U.S. Bureau of Economic Analysis recently revised its methodology for calculating the contribution of specific industries to GDP. See U.S. BEA (1996).

Figure 8-6.
Sectoral shares of U.S. GDP



NOTE: Services-producing industries consist of transportation and public utilities (including communications); wholesale trade; retail trade; finance, insurance, and real estate; personal and professional services; and other services. Goods-producing industries consist of agriculture, forestry, and fishing; mining; construction; and manufacturing.

See appendix table 8-3. *Science & Engineering Indicators – 1998*

Figure 8-7.
Change in share of U.S. GDP, by type of service industry: 1959-94



NOTES: Transportation and public utilities category includes communications. Professional services category includes business, health, legal, educational, social, and miscellaneous.

See appendix table 8-3. *Science & Engineering Indicators – 1998*

such as health and education. The share of GDP accounted for by wholesale and retail trade actually declined from 1959 to 1994, while personal services and transportation and utilities remained essentially unchanged. (See figure 8-7.) In contrast, FIRE's share of GDP grew by 4.8 percentage points, while that of professional services increased by 7.1 percent-

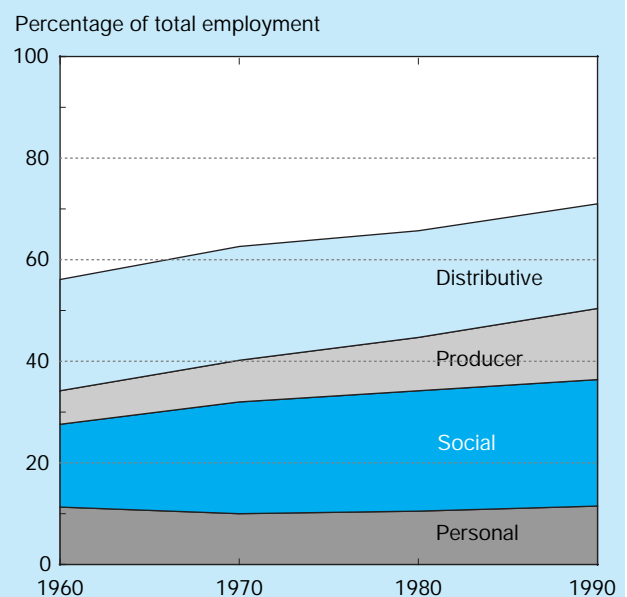
age points. Employment data reflect the same structural shift in the economy as GDP data. From 1960 to 1990, employment in the service sector grew from one-half to two-thirds of total U.S. employment, with growth strongest in producer services (FIRE and professional services) and social services, particularly health care. (See figure 8-8.)

IT has not, however, been empirically linked in any definitive way to the expansion of the service sector. In a detailed study of several key service industries (banking, insurance, air transport, and telecommunications), the National Research Council concluded that although the benefits of IT for individual industries could be qualitatively described, IT could not be causally linked to gross product output of the individual industry for methodological reasons (NRC 1994a).⁸ Two observations are worth making, however. First, based on case study evidence and expert reviews, it is unlikely that the expansion of the air transport, banking, finance, and trade industries would have been as significant in the absence of IT (NRC 1994a). In this sense, IT acted as a technological precondition for growth in many service industries.

Second, IT is unevenly distributed throughout the economy and is particularly concentrated in the service industries that have experienced rapid expansion. This suggests that IT is instrumental to the delivery of many services, and that growth

⁸Specifically, IT investment impacts in the 1980s cannot be isolated from the effects of many market, industry, and economic factors such as the deregulation of banking, telecommunications, and air transport.

Figure 8-8.
Changing share of U.S. service industries in total U.S. employment



NOTE: Social services include health, education, and nonprofit. Producer services include finance, insurance, real estate, and professional services. Distributive services include transportation, communication, and wholesale and retail trade.

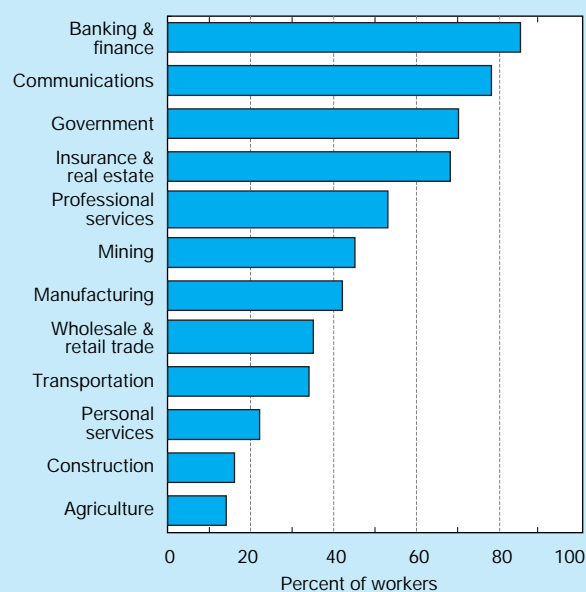
See appendix table 8-4. *Science & Engineering Indicators – 1998*

in services fuels demand for IT (and vice versa). For example, only 14 percent of workers use computers in agriculture, but 85 percent do so in banking and finance. (See figure 8-9.) Investments in IT similarly vary among industries. For example, the communications industry invests five times as much in IT as would be expected given the size of this sector relative to overall GDP. (See figure 8-10.) The disparity in the relative presence of IT among industries indicates that IT is clearly more critical for some types of business activities than others, and thus may be said to be responsible—in part—for the growth of those industries.

IT and Employment

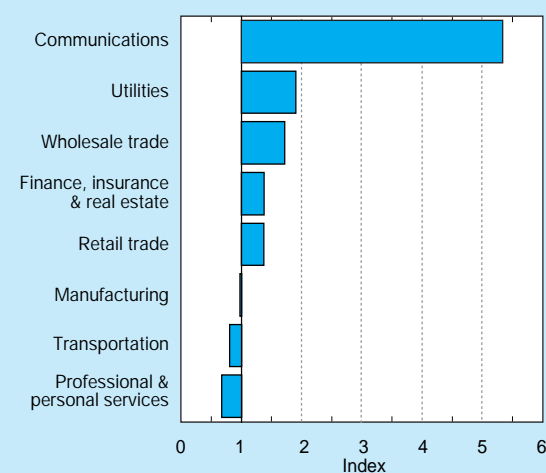
IT has demonstrable benefits for employment and skill levels, although not unequivocally so. Evidence indicates that IT contributes to growth in demand for labor, as well as an overall skill upgrading in the workplace. Computerization of the workplace appears to have enlarged the wage gap between workers with a college education and those with a high school education or less. With respect to the impact of IT on individual workers' health and emotional well-being, the record is mixed. While the number of IT-related health disorders is clearly on the rise, trends may be in part a socio-psychological phenomenon. Computerized surveillance and monitoring of employees may lead to greater stress and alienation in the workplace, but not necessarily: evidence suggests that IT may increase workers' sense of worth, accomplishment, and job autonomy.

Figure 8-9.
Percentage of workers who use a computer at work, by selected industry: 1993



See appendix table 8-5. *Science & Engineering Indicators – 1998*

Figure 8-10.
Index of IT investments, by industry: 1991-92



NOTE: Index represents industry's percentage share of information technologies (IT) investments relative to industry's share of GDP. An index of 1.00 reflects no over- or under-investing in IT relative to the size of the industry. Investments in IT are for hardware only.

See appendix table 8-6. *Science & Engineering Indicators – 1998*

Aggregate Employment

Establishing the net effect of IT on aggregate U.S. employment is difficult for one primary reason: IT is both labor-creating and labor-saving. As new jobs are created in some industries and occupational classes, they are lost in others. For example, banking employment has declined by 100,000 workers since its peak in 1990; analysts attribute this trend in part to the growing use of ATMs (Morisi 1996). IT-driven employment losses are, however, also offset by employment expansion in new industries such as computer and data processing services. Isolating the employment effects of IT from other factors—such as business cycles, industry conditions, and labor mobility—is problematic.

In an evaluation of the research on employment impacts of technology, the National Academy of Sciences concluded that the displacement effects of IT were indeterminate, and depended heavily on conditions in individual firms and industries. Because the nature of the research was so varied and the findings often contradictory, the Academy concluded that

the contrasting results of these studies...illustrate the sensitivity of empirical estimates of the employment impacts of [IT] to detailed assumptions concerning diffusion rates, technological improvement, and the organization of manufacturing and production processes (Cyert and Mowery 1987, p. 292).

Employment trends in key IT-related sectors further illustrate the difficulty of establishing the overall employment effects of a new technology. Employment in IT-producing industries is projected to nearly double from 1986 to 2006. (See text table 8-3.) Yet this trend is driven almost exclusively by growth in computer and data processing services (including prepackaged software), the third fastest growing industry in

Text table 8-3.

Employment in information technology-producing industries
(Thousands)

SIC code/industry	1986	1996	2006
Total	1,963	2,450	3,778
357 Computer and office equipment	469	363	314
366 Communications equipment	296	269	255
367 Electronic components	610	610	700
737 Computer and data processing services	588	1,208	2,509

SIC = Standard Industrial Classification

NOTE: Data are projected based on a moderate growth scenario.

SOURCE: U.S. Bureau of Labor Statistics, *Monthly Labor Review* (November 1997).*Science & Engineering Indicators – 1998*

terms of employment. Employment in two of the three IT-producing industries has been declining rather steadily since the early 1980s. Thus, trends in one sector mask patterns in another, much the way that the expansionary effects of IT could mask displacement effects within specific industries or occupations (and vice versa). For a discussion of trends in IT occupations see chapter 3, “Science and Engineering Workforce.”

Skill Impacts and Wages

Assumptions about the information society and post-industrial economy suggest that the development of IT should increase the demand for workers who manipulate and analyze information relative to the demand for non-knowledge workers or those who simply enter and collate data. Yet there is a persistent popular fear of the deskilling effects of IT, a fear that automation will reduce the demands on an individual’s conceptual talents and facility with machinery, equipment, and tools. Individual case studies of specific industries, occupations, and information technologies clearly illustrate that deskilling and skill upgrading take place simultaneously (for reviews, see Attewell and Rule 1994, and Cyert and Mowery 1987). On balance, however, several studies—using different data sets and methodologies—suggest that no overall lessening of skills is occurring in the workforce, and that upgrading may be widespread.

For example, Castells (1996) finds that employment in managerial, professional, and technical classes has been expanding at a rate faster than in non- and semi-skilled occupations. After an extensive review of trends in occupational categories, he concludes that:

The widespread argument concerning the increasing polarization of the occupational structure of the information society does not seem to fit with this data set...I am objecting to the popular image of the information economy as providing an increasing number of low-level service jobs at a disproportionately higher rate than the rate of increase in share of the professional/technical component of the labor force (p. 219).

Howell and Wolff (1993) conclude much the same. Using detailed data on the cognitive and motor skills required for specific occupations from 1959 to 1990, they found that skill restructuring (principally upgrading) in the labor force began in the 1970s and continued in the 1980s in patterns that “are broadly consistent with what one might expect from the rapid expansion of new [information] technology” (p.12). They also found that the demand for the most cognitively skilled information occupations grew more rapidly than for other occupations during some periods. Analyzing data from the Annual Survey of Manufacturers, Berman, Bound, and Griliches (1994) document a significant skill upgrading throughout the manufacturing sector over the 1980s; they attribute the trend in part to computerization of the workplace. Their findings indicate a distinct shift in the demand for labor from less skilled to more highly (cognitively) skilled labor in the United States, a shift that has been linked theoretically and empirically to the diffusion of IT.

Autor, Katz, and Krueger (1997) similarly find evidence that computerization of the workplace may explain from 30 to 50 percent of the additional growth in demand for labor from 1970 to 1995, compared to growth from 1940 to 1970. They find that the increase in the rate of growth for skilled labor since 1970 is driven by rapid skill upgrading in industries that are the most computer-intensive (e.g., those that have the highest levels of computer investment per worker and the largest growth in the proportion of employees who use computers, and those in which computers account for a larger share of total investment). This study finds that those industries that experienced the largest growth in computer use also tended to shift their employee mix from administrative and support workers toward managers and professionals (a finding consistent with Castells 1996). Nonetheless, more systematic insight into which jobs are upgraded (or deskilled), and what happens to individuals whose jobs are deskilled, can provide a better sense of the organizational dynamics surrounding IT and their ultimate employment impacts.

Assumptions about the IT-skill upgrading relationship extend one more step, and also associate wage gaps with computerization in the workplace. Higher wages are attributed to the higher demand for computer-skilled labor, and lower wages are thought to reflect the absence of computer skills (see Bresnahan 1997 for a discussion of this literature). Autor, Katz, and Krueger (1997) support this thesis; as do Berman, Bound, and Griliches (1994).

However, Howell (1997) refutes the argument that skill mismatch is responsible for wage stagnation among less skilled workers by identifying a crucial anomaly in labor market behavior: employment in *low-skill* occupations is declining relative to more highly skilled jobs, but the proportion of *low-wage* workers is actually increasing. Bresnahan (1997) also provides an important critique of the research and empirical evidence on the impact of IT on the demand for skilled labor and wage gaps. He reviews alternative research that indicates that the actual use of IT (particularly PCs) on the job is inconsistent with assumptions about job enrichment,

and concludes that “there is little complementarity between highly skilled workers and PC use, certainly not enough to affect skill demand.”

IT and the Worker

While IT may affect the individual worker in any number of ways, two particular effects are worth attention because of their negative physical and psychological aspects: the health hazards associated with the use of IT, and the emotional and behavioral consequences of workplace surveillance and monitoring.

IT is particularly associated with repetitive motion injury, even though a variety of other negative health effects are common, including eyestrain and a complex of musculoskeletal disorders (Huff and Finholt 1994). IT-based repetitive motions include barcode scanning, data entry and keying, and keyboard typing, all of which can lead to carpal tunnel syndrome and tendonitis—sometimes to the point of permanent disability. Data from the Bureau of Labor Statistics (BLS) indicate that the incidence rate of repeated trauma disorder rose from 6.4 per 10,000 FTE (full-time equivalents) in 1986 to 41.1 per 10,000 in 1994.⁹ Although the manufacturing sector still accounts for the vast majority of these repetitive motion injuries, the number of repeated trauma disorders increased more than fivefold in the service sector between 1988 and 1992. Grocery stores, newspaper publishing, hospitals, and casualty insurance industries now rank among the 20 sectors with the highest incidence of the disorder, and BLS indicates several other service industries are “poised to enter the list,” including airline scheduling, department stores, and mail order retailers (U.S. BLS 1994). The intensive use of IT is clearly an occupational hazard for individuals prone to repetitive motion disorder, but some researchers have found that a number of social and organizational factors can influence both the incidence of IT-related repetitive motion trauma and its severity (Kiesler and Finholt 1994, and Rowe 1994).

Workplace surveillance and monitoring also raise issues concerning workers’ psychological health. The U.S. Office of Technology Assessment defined electronic workplace monitoring as “the computerized collection, storage, analysis, and reporting of information about employees’ productive activities” (1987, p. 27); and it includes such measures as keystrokes typed per minute, length of time on a phone call, and length of time away from a computer terminal. Workplace monitoring is estimated to have doubled from 20 percent of all office workers in the early 1980s to 40 percent in the early 1990s, and spending on monitoring software is believed to exceed \$1 billion (Aiello 1993).

The effect of workplace monitoring on the individual’s well-being and work performance is unclear. One study (Grant, Higgins, and Irving 1994) found that monitored customer service employees believed that good work perfor-

mance was quantity based, while nonmonitored employees focused on the quality of service and teamwork. Another analyst observed workers disconnecting phone calls if it appeared the caller would exceed the 22-second maximum time allotted by the firm to each call (Aiello 1993).

Overall, studies show that workplace monitoring may both increase and decrease productivity, and may or may not lead to greater stress, anxiety, isolation, and diminished work motivation. Actual outcomes depend on a variety of moderating factors in the workplace, including worksite, supervisor style, type and frequency of feedback, and the individual’s sense of control over the monitoring itself.¹⁰ Indeed, one study (on the impacts of IT on quality of worklife) concluded that although IT could intensify work pressures, it also enhances workers’ sense of worth, accomplishment, and autonomy (Danziger and Kraemer 1986). Van Alstyne (1997) nonetheless regards surveillance and monitoring with suspicion, and concludes that there is good reason to expect that “those suffering reduced autonomy due to IT will seek ways to subvert the system, for example, through sabotage, disuse, delay, use of alternative procedures, supplying inaccurate data, or sticking to the letter but disregarding the intent of the system” (p. 40).

IT and the Productivity Paradox

One of the most debated issues about the impact of IT on the economy is that of the “productivity paradox”—the inability to find a statistical association between IT investments and productivity in the private sector. Despite compelling reasoning and evidence about the highly positive effects of IT on competitiveness and cost reduction,¹¹ traditional econometric analyses fail to find any productivity benefits for IT, and some studies identify negative productivity impacts for IT investments. The meaning of these findings is subject to considerable debate, with most experts advising caution in interpretation of the data. Problems with measurement and organizational learning lags are two explanations commonly offered to make sense of the counterintuitive empirical findings. However, the most current research on the IT productivity paradox suggests that it may have “disappeared” in the early 1990s; some analysts argue that the paradox is primarily the result of overly optimistic expectations about IT’s economic effects.

The Empirical Studies

The IT productivity paradox was revealed by over 20 econometric analyses conducted and published between 1980 and 1990 (for detailed reviews, see Brynjolfsson and Yang 1996, and NRC 1994a). Regardless of the level of analysis chosen—the macroeconomy or specific industries and sectors—these studies demonstrated that there was no

⁹These data are from U.S. BLS’s Survey of Occupational Injuries and Illnesses and may be accessed from the Occupational Health and Safety Agency Web site <<<http://www.osha-slc.gov/ergo/chart3.html>>>.

¹⁰For a good overview of these issues and findings, see Aiello (1993).

¹¹See Bender (1986); Benjamin et al. (1984); Harris and Katz (1991); Malone, Yates, and Benjamin (1987); Porter and Millar (1985); Bradley, Hausman, and Nolan (1993); NRC (1994a); and Byrne (1996).

statistically significant, or even measurable, association between investments in IT and productivity.

The findings were troublesome not only because they contradicted strong expectations about positive effects, but also because productivity impacts apparently failed to materialize anywhere (not in services or manufacturing), by any measure (a variety of data sets and methods were used), or at any time (the studies collectively covered the late 1960s to the late 1980s). Findings of positive effects are reported in the literature, but this research represents one-time-only case studies of a single industry or small set of firms. The preponderance of the IT productivity research—which incorporates large and relatively comprehensive data sets at the firm, industry, and macro levels—consistently fails to demonstrate a significant positive impact by IT on productivity, regardless of sector or industry. Indeed, one widely cited study finds a negative correlation between investments in IT and multifactor productivity. Furthermore, this study identifies yet another anomaly: industries that are IT-intensive are more profitable than others; but within industries, such intensity is negatively associated with profitability (Morrison and Berndt 1990, and Berndt and Morrison 1995).

Two recent avenues of empirical analysis are, however, notable. Oliner and Sichel (1994) and Sichel (1997) report a small but positive association between IT and productivity using a growth accounting approach. Brynjolfsson and Hitt (1995 and 1996) find large and significant contributions by IT to productivity using a new firm-level database. Both sets of findings are highly suggestive about the nature of the IT productivity paradox. Sichel (1997) argues that it is primarily our expectations that are out of line with the long-term historical trends regarding both IT diffusion and the overall level of IT capital in the economy. Brynjolfsson and Hitt note that a full 50 percent of the variation in IT's contribution to marginal product can be accounted for by firm-level variables. This suggests that aggregate data are not likely to detect patterns in IT impacts, and that the effective use of IT is highly contingent upon the context of its use at the organizational level.

To elaborate, Oliner and Sichel find small but real contributions of computers to the economy. From 1970 to 1992, computer hardware contributed 0.15 percentage points to the total U.S. output growth rate of 2.8 percent. When software and computer-related labor are included, this contribution doubles to 0.31 percentage points for the period 1987 to 1993 (or 11 percent of total growth).¹² Other capital and labor inputs, as well as multifactor productivity gains, account for about 90 percent of the growth in U.S. output during this

period.¹³ The authors explain the small contribution of computers by observing that computing-related inputs are a very small portion of total capital and labor, and have only recently grown large enough to have a measurable impact. They conclude that “computing equipment can be productive at the firm level and yet make little contribution to aggregate growth, precisely because computers remain a relatively minor factor of production” (Oliner and Sichel, p. 286). Sichel (1997) expands on this argument by reflecting on trends in the diffusion of a variety of information technologies. He concludes that computing technologies are part of a 150-year trend toward greater information intensity in the United States, and that we should not expect the effects of computers to be large and sudden, but modest and part of a historical continuum.

Brynjolfsson and Hitt (1996) analyzed the impact of IT on marginal output using a new firm-level database and found large contributions of IT to marginal product for the firms in their study. Every additional dollar of computer capital stock was associated with an increase in marginal output of 81 cents, and every additional dollar spent on IT-related labor was associated with an increase in marginal output of \$2.62. Their earlier work also demonstrates that firm-level factors account for half of the variability in IT's marginal product contributions (Brynjolfsson and Hitt 1995). In contrast, previous studies indicate that increases in IT are not associated with increases in marginal output; Morrison and Berndt (1990) found a negative relationship between IT spending and marginal output.

Several factors may explain the dramatically different findings of Brynjolfsson and Hitt relative to the earlier productivity studies. The later time period of their study (1987-91); the use of a larger data set; more detailed, firm-level¹⁴ data; and the inclusion of IT-related labor (note that IT capital expenses are typically a small fraction of a firm's total IT-related costs) are all reasons why their findings are more positive than those resulting from earlier research. Using similar data and methods, other analysts have also found significant positive rates of return at the firm level, including Lichtenberg (1995) and Link and Scott (1998).

The studies by Oliner and Sichel, and Brynjolfsson and Hitt highlight the complexity of research into the effects of IT on productivity. Both sets of findings suggest that IT does have measurable payoffs for economic productivity, but the orders of magnitude are quite different. Macroeconomic impacts may be quite modest at best (as measured by Oliner and Sichel), whereas firm-level benefits may be more substantial (as measured by Brynjolfsson and Hitt). While they do not indicate

¹²Note that Jorgenson and Stiroh (1995), who also use a growth accounting approach, find an appreciably higher level of contribution by computing hardware to macroeconomic output. These authors estimate that computer hardware contributed 0.38 percentage points to the 2.49 percent growth rate from 1985 to 1992—more than double the 0.15 estimate provided by Oliner and Sichel. Differences are due in large part to the different time periods of the studies and to differing assumptions about depreciation rates. As with other economic analyses, assumptions can have a substantial impact on empirical estimates.

¹³Sichel (1997) asserts that there is no additional contribution of IT hidden in the multifactor productivity (MFP) estimate. MFP is a residual element that reflects technical and organizational changes that improve the efficiency of converting inputs into outputs, hence IT could contribute to gains that are captured by MFP. However, given the nature of growth accounting techniques, IT inputs would have to have a “supernormal” rate of return, and Sichel argues that there is no compelling evidence for such an assumption.

¹⁴Findings are based on a data set of 367 firms generating \$1.8 trillion in aggregate sales in 1991.

that the productivity paradox has been resolved, these findings do suggest that the relationship between IT and productivity may be changing. Explanations for the paradox and the lagged benefits of IT therefore require further exploration.

Explanations for the Paradox

There are a number of interpretations of the productivity paradox, most falling into one of three categories:

- ◆ There is no paradox—IT does have positive effects on business and economic performance, but we are not able to measure these effects easily.
- ◆ The paradox is real but temporary—our social and organizational ability to adapt to new technology lags the pace at which the technology is introduced.
- ◆ The paradox is real and not temporary—the implication of which is that IT has no beneficial consequence for the economy, and hence reflects substantial opportunity costs (that is, money spent on IT is better spent elsewhere).

This third interpretation is not explored in this chapter, since the weight of evidence suggests that there *are* meaningful impacts of IT, challenging measurement problems, and very real social lags.

Excluding disagreements about the quality of various data used in the IT productivity studies (which has implications for sources of error in the findings), there are still a number of core measurement issues.¹⁵ The first is, what constitutes IT? Is it capital investments only, or does it include labor, which represents the bulk of IT operating costs? Do IT capital investments include more than computers, and if so, what? The choices of what to count as an IT equipment expense include computing hardware and software, communications equipment, and a variety of office machines (such as photocopiers and some instruments). At present, there is little consistency among studies, and sources of IT investment data vary from aggregate government data to private survey-based firm data. One fundamental measurement issue is simply standardizing the definition of IT itself (labor, capital, and types of capital): standardized definitions can facilitate data collection, comparability across data sets, and cumulation of findings.

A second key measurement issue is how to assign dollar values to IT as a factor input. IT can be measured as a flow (annual expenses or purchases) or as a stock (the cumulation of equipment over time). In both instances, price deflators are required to compare stocks or flows over time by converting them to “real” dollars. IT equipment is especially problematic for establishing reliable deflators. For example, not only has the sales price of computing equipment been falling rapidly, but because quality has increased exponentially, existing computing stock becomes obsolete very quickly. The pace of technological change in information technologies greatly complicates analysts’ abilities to construct quality-

adjusted price deflators¹⁶ and appropriate depreciation rates; distortions in time-series data can significantly affect research outcomes by over- or undervaluing expenses and stocks in different periods.

A third measurement concern relates to output—specifically, how to measure the output of information processing. IT is used extensively for “activities” that do not result in tangible market outputs (e.g., accounting, scheduling, reporting).¹⁷ Consequently, it is difficult to assign a dollar value to the output of IT—a measurement that is crucial to accurate productivity analysis. This measurement challenge is exacerbated in the service sector, where output measures must also capture qualitative differences in services (Mark 1982 and Noyelle 1990); the problem is sufficiently severe that BLS does not report labor productivity for the software industry, a core IT sector (Goodman 1996). The potential for mismeasurement of services and information processing outputs, as well as IT as a factor input, is so troublesome that mismeasurement is usually cited as the primary explanation for the productivity paradox.

A fourth measurement issue deserves attention and has less to do with mismeasurement of a specific indicator (such as factor inputs and product outputs) than of measuring the wrong indicator to begin with. Studies of the applications and use of IT repeatedly demonstrate that IT benefits do not show up as classical efficiency gains, but as cost savings, improved inventory management, and qualitative improvements in customer service. These improvements reflect such dimensions as enhanced timeliness, performance, functionality, flexibility, accuracy, precision, customization, cycle times, variety, and responsiveness regardless of whether the output is a product or service or the consumer is an original equipment manufacturer, a distributor, or an end user (NRC 1994a; Byrne 1996; and Bradley, Hausman, and Nolan 1993). These qualitative dimensions are much more likely to show up as downstream benefits to the consumer (Bresnahan 1986) or as greater competitiveness for a firm—an outcome known as a “distributional effect” (Banker and Kauffman 1988, Baily and Chakrabarti 1988, Brynjolfsson 1993, and Porter and Millar 1985). In addition, Weill (1992) has found that the type of information processing (transaction) matters. In a study of valve manufacturers, data processing could be associated with productivity gains, but general business systems (like sales and marketing support) could not.

Institutional Lags

Another compelling explanation of the productivity paradox argues that it is a real but temporary phenomenon. Sociologists and economic historians have long argued (very cogently) that society’s ability to fully exploit a new technol-

¹⁵The measurement problems are substantial and are discussed in detail elsewhere (Brynjolfsson 1993, Baily and Chakrabarti 1988, Griliches 1997, NRC 1994a, and Oliner and Sichel 1994).

¹⁶Note that the issues surrounding the measurement of services and their impacts are comparable to the methodological problems of measuring services and their impacts. Outputs are often intangible, quality is difficult to account for, and constructing R&D-specific price deflators is a complicated task. For more on R&D measurement issues, see NSB (1996), chapter 8.

¹⁷“Activities” are defined as repetitive and structured sets of work tasks; see NRC (1994a).

ogy lags—often by decades—the introduction of the technology itself (Ogburn 1964 and Perez 1983). Similarly, in organizational change scholarship, analyzing institutional resistance to change (technological or otherwise) is the coin of the disciplinary realm. In theory and in practice then, as humans and their institutions become more accustomed to IT, productivity and other aspects of performance should improve.

There is a good deal of evidence to support this argument. Important technological analogies for IT are electric generators and the electric power infrastructure. David (1989) found that it took nearly 20 years for the electric generator—an invention comparable to IT in scope and consequence—to have a measurable effect on industrial productivity; Friedlander (1997) found that historically it has been difficult to measure the benefits of most infrastructure technologies. With respect to IT specifically, firm-level performance can vary considerably, and the effective use of IT is apparently contingent upon a number of moderating variables at the organizational level—including strategy, leadership, attitudes, organizational structure, appropriate task and process reengineering, individual and organizational learning, and managerial style and decisionmaking (Cron and Sobol 1983; Curley and Pyburn 1982; Graham 1976; Thurow 1987; Landauer 1995; Tapscott 1996; Danziger and Kraemer 1986; Khosrowpour 1994; Banker, Kauffman, and Mahmood 1993; and Allen and Morton 1994). Other analysts argue that information technologies themselves are the cause of low productivity, since they are not necessarily user-friendly or well-designed. In this respect, evidence suggests that technological adaptation to social need has a lagged effect as well (Eason 1988, Landauer 1995, and Forester 1989).

The productivity paradox may thus be partially explained, but it does not dispel the observation that even as IT is radically changing the nature of some business activity, that activity does not necessarily get translated into greater efficiency or economic welfare. The banking industry is a good case study of the complexity of the paradox, and also of the possibility that the paradox may have “vanished” in the early 1990s for some sectors.

IT and the Banking Industry

The banking industry is one of the oldest users of information technologies—in the early 1950s, Bank of America was the first commercial user of mainframe technology (Morisi 1996). Yet the banking industry reflects most of the empirical dilemmas associated with measuring the impacts of IT: heavy investments in IT; slow (or no) visible improvements in productivity until relatively recently; and impacts that reflect quality improvements, rapid product diversification, and substantial growth in volume of commercial transactions.

IT has clearly changed both the structure and service quality of banking, and appears finally to have a positive impact on cost reduction. But it has taken decades to achieve these results, and traditional productivity analyses still do not de-

tect positive associations between IT investments and productivity in the commercial banking sector.

Banking industry investments in IT increased substantially from the late 1960s to the late 1980s. (See figure 8-11.) Annual investments in IT (in constant 1982 dollars) grew from \$0.1 billion in 1969 to \$1.6 billion in 1980 to \$13.8 billion in 1989. By 1989, the banking industry was annually investing more funds in IT than were all of the other major service industries except telecommunications. The banking industry invested more in IT relative to its gross product output than the insurance, health care, air transport, telecommunications, wholesale trade, and retail trade industries. (See text table 8-4.)

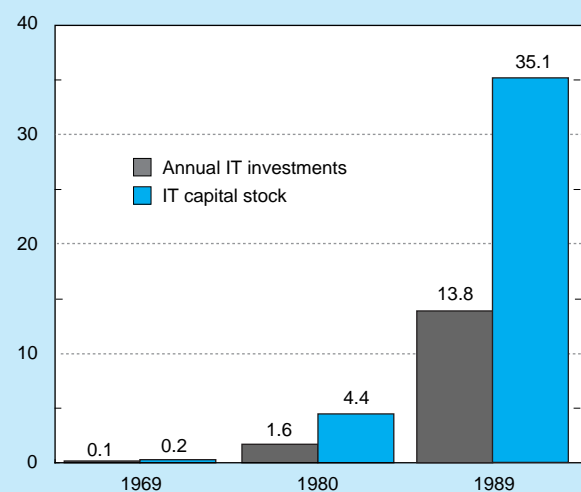
IT uses are diverse in the banking sector. Initial applications included accounts management and check processing via magnetic ink character recognition. Automated clearing-houses, which enabled electronic funds transfer (EFT), were introduced in the early 1970s and ATMs in the late 1970s. EFT, ATM, and telephone transaction capabilities have replaced a wide variety of paper and in-person transactions in banking, including account deposit and withdrawals, accounts management, credit applications and approvals, cash dispensing, funds transfers, point-of-sale transactions, credit card payments, and consolidation of banking operations.

Impacts on Productivity

Reviews of the traditional econometric productivity literature indicate that IT investments by the banking industry do not systematically result in measurable, positive productivity

Figure 8-11.
IT investments by the banking industry

Constant 1982 billions of dollars



NOTE: IT is information technologies.

SOURCE: National Research Council, *Information Technology in the Service Society* (Washington, DC: National Academy Press, 1994).

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Text table 8-4.
Investments in information technologies by
selected service industries: 1989

Industry	Investments in constant 1982 dollars (in billions)	Investments as a percentage of industry gross product output
Banking	13.8	19
Telecommunications	13.8	14
Wholesale trade	11.6	4
Retail trade	10.6	3
Insurance	6.2	17
Health care	3.6	2
Air transport	3.0	9

SOURCE: National Research Council, *Information Technology in the Service Society* (Washington, DC: National Academy Press, 1994).

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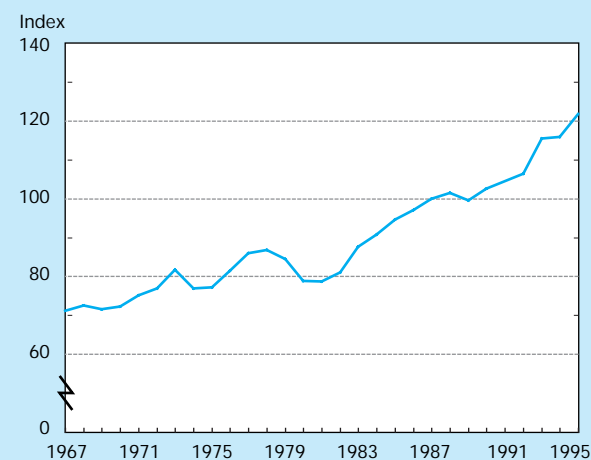
impacts. Major cross-sector studies (see Brynjolfsson and Yang 1996 for reviews) do not detect positive productivity returns for IT in the banking industry, and Franke's (1989) study of the financial sector (insurance and banking combined) suggests that IT is associated with negative productivity impacts. However, Brand and Duke (1982) do find productivity growth of 1.3 percent per year attributable to computers. Using qualitative evidence and interviews with chief executive officers, the National Research Council attributed the lack of productivity impact to a variety of factors. One is the ever present measurement issue: measures of output in the banking industry are extrapolated from employment data by the U.S. Bureau of Economic Analysis and estimated from indices of financial transactions (loans, deposits, and so forth) by BLS. Neither procedure fully accounts for the volume of banking transactions or wider variety of financial services; the inherent difficulty of measuring commercial banking output seriously qualifies productivity analysis using aggregate data sets.

Note, however, that labor productivity has been steadily improving in the banking industry. (See figure 8-12.) Morisi reports that "during the 1973-93 period, commercial banks had the highest long-term growth in productivity than any of the measured finance and service industries" (1996, p. 30). The difficulty is in empirically linking these improvements to IT.

A second reason for the apparent lack of IT-led productivity growth in this industry relates to problems with early generations of information technologies and organizational adaptation. The National Research Council study reported that:

early applications of IT proved to be costly and cumbersome. Software and equipment had to be updated and replaced frequently...IT systems required large amounts of tailoring, training, upgrading, and updating. Cost control, management skills, and productivity tracking systems lagged behind the new technologies in a rapidly changing competitive marketplace...The result was that tangible paybacks from IT investments were delayed (NRC 1994a, pp. 80-81).

Figure 8-12.
Commercial banks output per employee
(Index: 1987 = 100)



See appendix table 8-10. *Science & Engineering Indicators – 1998*

Other Business Impacts of IT

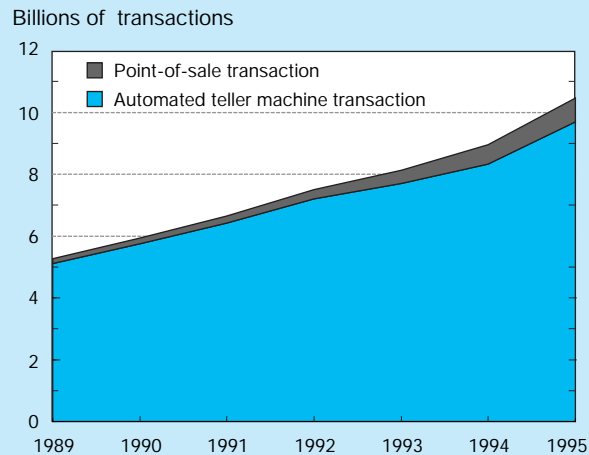
The significance of IT emerges in areas of business impact other than conventionally measured productivity gains. Three types of effects are worth particular note: the expansion of banking products and services, time and cost savings, and competitive positioning.

Banking products and services have proliferated with the use of EFT, ATM, telephone transactions, and automated credit and loan procedures. Banks thus process billions of transactions a year—everything from clearing individual checks, to ATM cash dispersal, to account inquiries, to loan approvals—a volume of interactions that would simply not be possible without automation. For example, the Clearinghouse for Interbank Payment Systems was processing nearly \$2 trillion worth of transactions *per day* by the late 1980s, and Visa's capacity for authorizing credit card transactions increased from 30,000 per day in 1978 to 1.4 million per day in 1991 (NRC 1994a, pp. 83-84). Bresnahan (1986) estimates that the benefits to consumers of the use of mainframe computers for financial services was five times greater than the investments in the computers themselves.

The qualitative improvement in customer convenience, ease, and scope of access to financial resources is reflected in the overall growth of electronic transactions. Figure 8-13 illustrates the expansion of electronic (ATM and point-of-sale) transactions in the United States; the number of electronic cash transactions and payments for goods and services was more than 10 billion in 1995, compared to just over 5 billion in 1989.

Time and cost savings for the industry are also notable. For example, Mellon Bank reduced the average processing time of customer complaints by 20 days when it installed an integrated document system; Visa reduced its processing time for electronic credit card authorizations from 5 minutes in

Figure 8-13.
U.S. electronic funds transfer volume



SOURCE: U.S. Bureau of the Census, *Statistical Abstract of the United States 1996*, table 795 (Washington, DC: U.S. Government Printing Office, 1996). Data are proprietary to Faulkner & Gray (Chicago).
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1973 to 1.1 seconds in 1991; and the Bank of Boston reduced its staff requirements by 17 percent and increased its transaction volume by 80 percent when IT allowed the bank to consolidate its mainframe operations (NRC 1994a, pp. 83-84). The American Bankers Association estimates that ATM transactions cost 27 cents compared to \$1.07 for a human teller, and telephone transactions cost about \$0.35 compared to \$1.82 for a phone call processed by bank personnel (Morisi 1996). In a study of 759 banks, Alpar and Kim (1991) found that a 10 percent increase in IT expenses led to a 1.9 percent decrease in total bank costs.

Although the productivity measures do not find a link between banking industry output and IT investments, it is important to note that while the volume of financial transactions has been increasing at a dramatic rate, employment in the sector has been falling. By 1996, employment in the commercial banking industry was 100,000 employees below its historic peak in 1990. During the same period, the number of ATM transactions doubled to more than 10.5 billion.

IT is of value to the banking industry not only for time savings, cost reductions, and customer services, but for the ability to give individual banks a competitive advantage or the ability to maintain a competitive position. Deregulation of the industry in 1980 led to intense rivalry among institutions, and expanding automated services was one way of attracting depositors and customers. Thus Banker and Kauffman's (1988) study of 508 branch banks found that ATMs were essential to maintaining market share and customer base—not necessarily to reducing costs.

Implications for IT Metrics

The banking industry illustrates many of the issues involved with establishing useful metrics for analyzing the economic

impacts of IT. Not only are there problems with measuring the output of this industry in a meaningful way (productivity estimates require output estimates), but there is the issue of what to measure in the first place. IT clearly provides “value added” in a range of consumer and producer activities that are not captured by productivity analysis, such as convenience, scope of services, access, time savings, transaction volume, and transaction cost reductions. The challenge is to select one or two representative measures of impact and track their performance over time.

The industry may have experienced a long learning curve in terms of adaptation to new information technologies. Insight into how banks reengineered their organizations, management strategies, and work tasks could inform IT strategies in other industries and shorten the lag between the time a technology is introduced and the time it begins to measurably enhance business performance.

IT, Education, and Knowledge Creation

Information technologies are likely to have a substantial impact on the entire spectrum of education by affecting how we learn, what we know, and where we obtain knowledge and information. IT influences everything from the creation of scientifically derived knowledge (see “IT, Research, and Knowledge Creation”) to how children learn in schools; life-long learning by adults; and the storage of a society's cumulative knowledge, history, and culture. Because IT networks create remote sources of instruction and geographically distributed information resources, learning, knowledge generation, and information retrieval are no longer confined to the traditional spaces of laboratories, schools, libraries, and museums.

As a consequence, new education activities such as distance learning are clearly on the rise.¹⁸ (See chapter 2, “Distance Learning and Its Impact on S&E Education.”) In 1984, fewer than 10 states had distance learning facilities, but by 1993 all 50 states did. In the same year, the 20 largest providers of satellite-based instruction purchased 75,000 hours of satellite transponder time; assuming that coursework would be broadcast during a 40-hour week, these top 20 providers purchased the equivalent of 36 instructional years (Katz, Tate, and Weimer 1995).¹⁹ Internet Distance Education Associates estimates that more than 100 U.S. colleges and universities offer courses over the Internet;²⁰ National Technical University, a satellite TV educational institution, has over 800 receiver sites (Katz, Tate, and Weimer 1995). Also new are digital

¹⁸“Distance learning” refers to education that takes place via electronic means, such as satellite television or the Internet. There is no single organization responsible for certifying or monitoring distance education in the United States, so there are no uniform statistics or a centralized directory of distance learning providers.

¹⁹Note that there are more than 100 major providers of satellite-based instruction.

²⁰Data available from <<<http://www.ivu.com>>>.

IT, Research, and Knowledge Creation

IT has fundamentally enhanced the conduct of scientific research, data modeling and analysis, and the creation of scientifically derived knowledge. The most pervasive change is the emergence of the “global laboratory”—Internet connections now allow scientists to control instrumentation from a distance, share research findings instantaneously with other scholars around the world, and develop international databases and collaborations. The research applications of networking are extensive (see NRC 1993 and 1994b); IT has gradually eroded the geographic constraints on the conduct of research and knowledge cumulation.

High-speed computing and advanced software applications have also enhanced the analysis of scientific data and drastically shortened the amount of time required to perform certain scientific tasks. For example, data visualization provides dynamic, three-dimensional modeling of complex systems data such as fluid dynamics, while imaging technology provides visual tracking of such minute cellular changes as embryo development. In biology, major advances in rapid gene sequencing and protein mapping are the direct result of highly advanced computational programs (*Science* 1996).

IT also provides knowledge we would not otherwise have—satellite-based technologies are particularly noteworthy. For example, the global positioning system allows geologists to measure precise movements in the earth’s crust, thus identifying communities that are vulnerable to earthquakes and aiding in earthquake prediction (Herring 1996). Global climate change modeling similarly owes its advances to satellite-based data collection and transmission; in turn, more detailed knowledge of historical climate patterns has improved our understanding of some infectious diseases and epidemics (Colwell 1996).

Advancement in scientific knowledge is not limited to higher education. An innovative IT-based program includes precollege students from around the world in the research process. The Global Learning and Observations to Benefit the Environment (GLOBE) Program provides environmental science education to K-12 students in more than 3,500 schools and 45 countries. These students collect environmental data for use by the scientific community in research on the dynamics of the earth’s global environment. Students report data on the Web, generate graphical displays and contour maps, and interact with international research scientists as well as other GLOBE students (Finarelli n.d.).

museums, which allow millions of individuals access to history and culture they would not otherwise have.²¹ These include Fisk University’s collection of 7 million African American artifacts; the Vatican’s 600-year-old collection of over 1 million books and manuscripts (including the only known copies of many historically significant documents); and the Library of Congress’s American Memory Collection of documents, films, photographs, and sound recordings (Memmott 1997). Libraries are undergoing comparably profound digital revolutions (see “IT and the Changing Nature of Libraries”).

Because of the growing role of IT in learning and in expanding the scope of educational resources, many people are concerned about the accessibility of information technologies to the nation’s schools and the effects of these technologies on students—particularly K-12 children. This section looks at the diffusion of IT in U.S. elementary and secondary schools as well as the effects of computer-based instruction on student achievement. Inequities in student (and household) access to IT are considerable; these are addressed in the final section of this chapter, “IT and the Citizen.”

IT and Precollege Education

National pressures to increase the scope and use of information technologies in U.S. elementary and secondary schools are persistent (PCAST 1997, NIIAC 1995, The Children’s Partnership 1996, and McKinsey and Company 1995). In most instances, the primary reason for greater emphasis on IT is adequate job training, although there is notable concern over avoiding a stratified society in which the “information haves” are divided from the “information have-nots.” Greater use of IT at the precollege level is frequently understood as the training students need to be competent members of the information society and to enjoy an information-enhanced quality of life.

Assumptions about the educational, employment, and life-enhancing benefits of IT are not universal, however. *Silicon Snake Oil: Second Thoughts on the Information Highway* by Clifford Stoll (1995) represents one popularized critique of claims about the social payoff of IT (including educational benefits). Additionally, scholar Larry Cuban (1994) has repeatedly raised the question “should computers be used in classrooms?”; and journalist Todd Oppenheimer (1997) has explored the significant educational opportunity costs that may emerge with greater spending on IT. The fundamental dilemma of computer-based instruction and other IT-based educational technologies is that their cost effectiveness compared to other forms of instruction—for example, smaller class sizes, self-paced learning, peer teaching, small group learning, innovative curricula, and in-class tutors—has never been

²¹This “digitizing of history”—particularly that of perishable or fragile photographs, artwork, documents, recordings, films, and artifacts—represents a socially invaluable preservation function and allows people to view items that could never be displayed publicly. Note that the Library of Congress Web site <<<http://www.loc.gov>>> had over 42 million hits in April 1997 alone (Memmott 1997).

IT and the Changing Nature of Libraries

Historically, the public library has played a central role as an information resource in American communities. Gallup polls indicate that the majority of American adults still regard the public library as a key center for educational support, independent learning, research, community information, and reference resources (NRC 1994b). Not surprisingly, the United States has the most extensive public library system in the world, and more than one-half of the adult population and three-quarters of adolescent children use public libraries.

With the advent of new information technologies, the nature of library information resources is changing. Electronic information services are increasingly common; and CD-ROM databases, remote database searching, and on-line catalogs are available in more than two-thirds of the U.S. public libraries that service communities of 100,000 or more individuals. Networks allow libraries to leverage their resources through interlibrary loans and have stimulated the development of the “digital library,” a concept that reflects the digitization of library resources and collections. The ability to store and transmit mixed-media resources (see the text discussion of digitized museums) gives greater significance to nonprint information resources (such as sound recordings and visual images) and has stimulated librarians to expand and diversify their information management skills. Stewardship of library information has moved from a “just-in-case” model of on-site materials to a “just-in-time” model of resource access and sharing.

The Internet has significantly expanded the resource base of public libraries. Library-based access provides a number of advantages to Americans. First, it is an affordable, equitable, and ubiquitous point of access for most individuals. Second, locally developed databases and network linkages are highly responsive to the needs of the local community and can facilitate more effective network use. Third, the library can act as an electronic gateway to information for people who would not otherwise have access to the Internet.

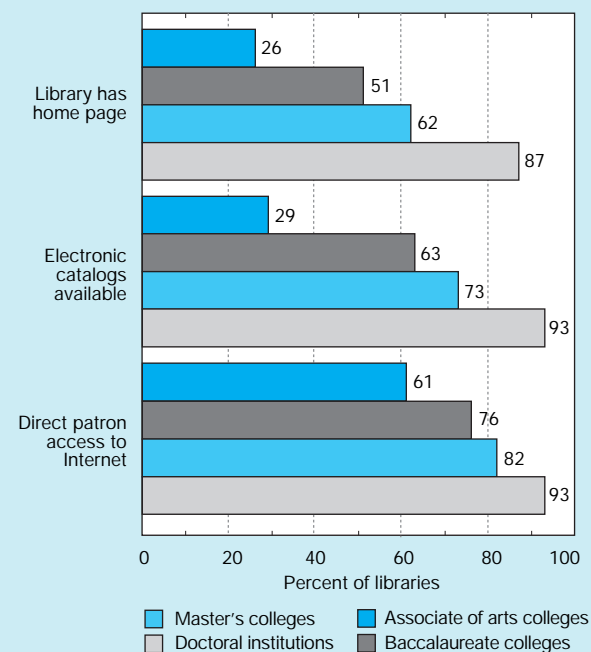
Barriers to library connectivity exist, as evidenced by the relatively low level of library linkage to the Internet. Less than half of public libraries (45 percent) were connected to the Internet in 1996, a figure that masks considerable variation by community size: less than one-third of libraries in communities of less than 5,000 individuals had Internet access (31 percent), compared to the 82 percent of libraries serving metropolitan areas over 1 million people. For the roughly 500 libraries that serve metropolitan areas of 100,000 or more, 93

percent offer Internet access to the library staff, and one-half offer access directly to patrons (ALA 1996). As access fees decline, it is likely that more libraries will connect to the Internet: representatives of more than 70 percent of those libraries not now connected say they plan to do so within the next year (ALA 1996).

In contrast, academic libraries are highly “wired,” but with variations by type of institution. Associates degree colleges lag other institutions of higher education on most dimensions of electronic access to resources, including direct patron access to the Internet, the availability of electronic catalogs, and the library’s development of its own home page for students. (See figure 8-14.)

For more information on the substantial changes in library activities related to the use of IT, see NRC (1994b), Lyman (1996), and Lesk (1997).

Figure 8-14.
Academic library access to electronic resources: 1996



SOURCE: American Library Association, “How Many Libraries Are on the Internet?,” LARC Fact Sheet No. 26 <<<http://www.ala.org/library/fact26.html>>> (1996).

proven (Rosenberg 1997, Cuban 1994, and Kulik and Kulik 1991). Although real IT learning benefits have been measured and demonstrated, whether the magnitude of these benefits is sufficiently large to justify limiting other school curricula and programs is open to question.

The budget issues and educational opportunity costs associated with IT are not trivial. In a report to the U.S. Advisory Committee on the National Information Infrastructure, McKinsey and Company (1995) estimated that about 1.3 percent of the national school budget is spent on instructional technology. Heightening the level of IT in K-12 public schools would require raising this share to as much as 3.9 percent, depending on the degree of IT intensity desired.²² This spending increase is for hardware only, and does not include IT operational expenses or the cost of teacher training, a significant factor in the effectiveness of computer-based instruction (U.S. OTA 1995, McKinsey and Company 1995, Ryan 1991, and PCAST 1997). Yet inflation and the expanding school-age population account for almost all growth in school budgets; the McKinsey report states that only 1.6 percent of the growth in per student expenditures is available for IT and other discretionary spending, including building repair and maintenance, school security, teacher salaries, and the operating costs of IT hardware. Because school districts are under increasing fiscal stress, expanding IT resources could mean cutting other important programs. Oppenheimer (1997) details sacrifices in art, music, physical education, vocational trade (“shop”) classes, and textbook purchases that have been made for computers. The negative impacts of these sacrifices on learning and job skills are not usually considered in the growing emphasis on CBI. Also not considered is the potential decline of “collateral” and experiential learning that may occur as more instruction is shifted to the computer (Cuban 1994).

Our understanding of the learning impacts of CBI is primitive. The research reported below does find systematically positive learning benefits associated with computer use in schools, but the magnitude of the benefits is often modest and varies by level of education, characteristics of the learners, characteristics of the instruction and teachers, subject matter, and type of computer application. CBI is a broad category that captures computer-assisted instruction (typically drill-and-practice exercises or tutorial instruction), computer-managed instruction (the computer monitors student performance and progress and guides student use of instructional materials), and computer-enriched instruction (the computer functions as a problem-solving tool). Categories of software use are even more extensive and include generic information-handling tools, real-time data acquisition, simulations,

multimedia, educational games, cognitive tools, intelligent tutors, construction environments, virtual communities, information access environments, information construction environments, and computer-aided instruction (Rubin 1996). Software (courseware) for inquiry-based learning²³—the ultimate goal of most CBI advocates and the most cognitively demanding form of learning—is in short supply. This resource deficiency may be one cause of the limited measurable impacts of CBI on higher order thinking skills and learning (Kulik and Kulik 1991, PCAST 1997, and McKinsey and Company 1995).

Research data suggest that CBI appears to be most effective with rote learning at the elementary school level and in special education settings (that is, in remedial work, or with low achievers or those with learning disabilities). The impact of CBI on critical thinking and synthesis skills is much harder to demonstrate. Also unclear is how to maximize the effectiveness of CBI in the classroom: empirical studies often account for 40 or more contextual variables related to learning and instruction. Schofield (1995) sheds light on this contextual complexity of computers and learning in her detailed two-year case study of computer use at a typical urban high school. Her findings demonstrate how the social organization of the school and classrooms affect computer-related learning, behavior, attitudes, and outcomes. On balance, Schofield found that computers aggravated pre-existing differences between academically advanced and “regular” students, boys and girls, and college-bound and non-college-bound students.

Computer-based instruction clearly does not take place in a vacuum, but systematic understanding of the social and cognitive complexity of computer-based learning is limited. As the President’s Committee of Advisors on Science and Technology, Panel on Educational Technology, concluded,

Funding levels for educational research have been alarmingly low...In 1995, less than 0.1 percent of our nation’s expenditures for elementary and secondary education were invested to determine which educational techniques actually work, and to find ways to improve them (PCAST 1997).

Diffusion of IT in K-12 Education

Over the past 20 years, computers and other information technologies have been diffused widely in the U.S. K-12 educational system. Ninety-eight percent of all schools have at least 1 microcomputer for instructional use, and about 80 percent have 15 or more (see figure 8-5 earlier in this chapter). One-half of a school’s instructional computers are located in the classroom, 37 percent are located in computer labs, and approximately 13 percent are placed in other public

²²For example, ensuring adequate pupil-to-computer ratios and Internet connections to the school versus universal classroom deployment of full multimedia computers, Internet connections, and school networks. The McKinsey report details three alternative IT models and estimated costs.

²³Inquiry-based learning represents active learning on the part of a student rather than the passive assimilation of information “taught” by an instructor. Inquiry-based learning reflects active construction of models for conceptual understanding, the ability to connect knowledge to the world outside of the classroom, self-reflection about one’s own learning style, and a cultivated sense of curiosity. See Rubin (1996).

access rooms such as a library or media center. This distribution has not changed since the mid-1980s.²⁴

Estimates of the average number of computers per pupil in the early 1980s vary widely—from 42 to 125 students per computer; but data consistently indicate that the ratio now is approximately 10 or 11 students per computer (ETS 1997).²⁵ Disparities in student access are considerable, however. The differences in students per computer by state of residence range from about 6 pupils per computer in Florida to 16 in Louisiana. (See figure 8-15.)

Schools have also adopted other information technologies. For example, in 1996, 85 percent of schools had access to multimedia computers, 64 percent had Internet access, and 19 percent had satellite connections. (See figure 8-16.) Diffusion of these additional information technologies has been quite rapid. In 1992, only 8 percent of schools had an interactive videodisk, compared to 35 percent in 1995; 5 percent of schools had local area networks, compared to 38 percent in 1995; and only 1 percent had satellite dishes, compared to 19 percent in 1995. (See appendix table 8-7.)

School access to these technologies does not necessarily mean that they are used for instructional purposes, however. The National Center for Education Statistics reported that 65 percent of all public schools had Internet access in 1996, but only 14 percent of school rooms actually used for instruction were linked to the Internet (NCES 1997).²⁶ On a state-by-state basis, the number of schools with Internet access varies far more than the student-to-computer ratios. (See figure 8-17.)

A 1992 survey of elementary and high school principals indicates that the three most important reasons schools adopt computer technologies are to (1) give students the experience they will need with computers for the future, (2) keep the curriculum and teaching methods current, and (3) improve student achievement (Pelgrum, Janssen, and Plomp 1993). There are, however, notable differences in the ways in which computers are actually used: the higher the school grade, the more computers are used for computer training and the less they are used for teaching academic content. At the fifth grade level, 58 percent of CBI time relates to subject matter, and only 32 percent relates to computer skills such as word processing and spreadsheets. By 11th grade, more CBI time is spent on computer skills (51 percent) than academics (43 percent); instructional use for math and English drops from 35 to 14 percent.²⁷ (See text table 8-5.)

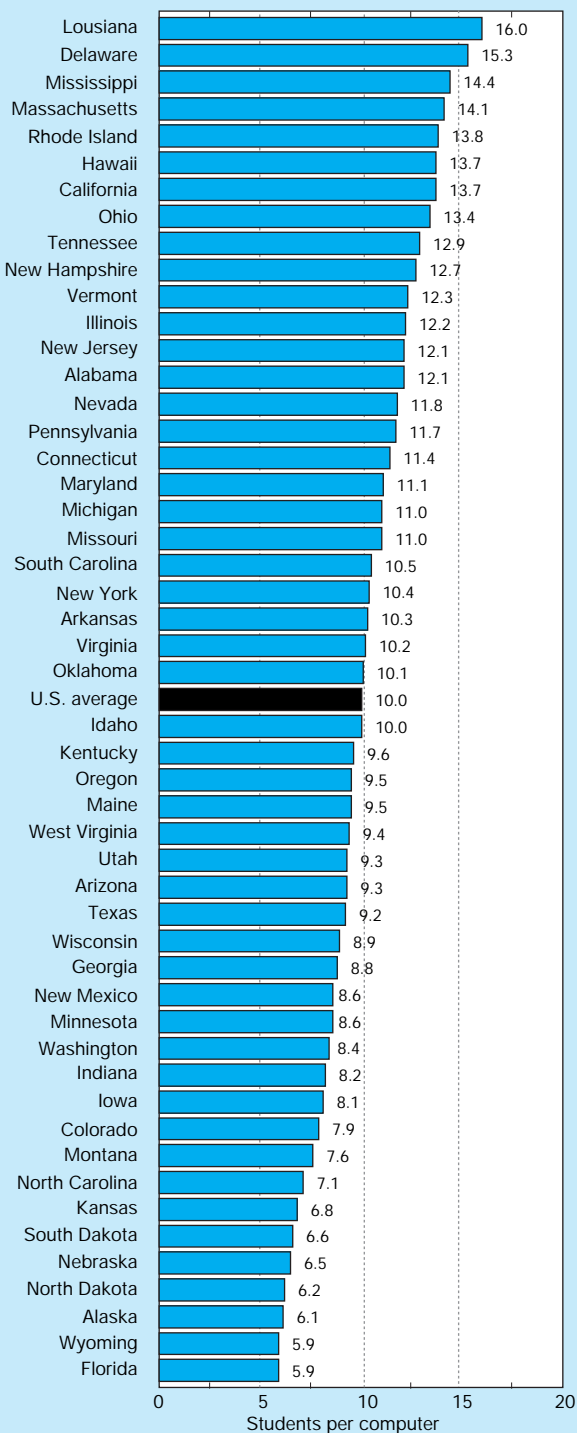
²⁴See U.S. Bureau of the Census (1996), table 262; these data are based on the Computers in Education Study conducted by the International Association for the Evaluation of Educational Achievement (see IEA n.d.).

²⁵See also U.S. Bureau of the Census (1996), table 261 (based on unpublished data from Market Data Retrieval), and table 262 (based on IEA n.d.).

²⁶There were also significant differences in Internet access based on minority enrollment. See chapter 1, figure 1-17 and related discussion, and appendix table 1-25.

²⁷The President's Committee of Advisors on Science and Technology has recommended that the primary focus of computer-based instruction be content-oriented rather than skills training. See PCAST (1997).

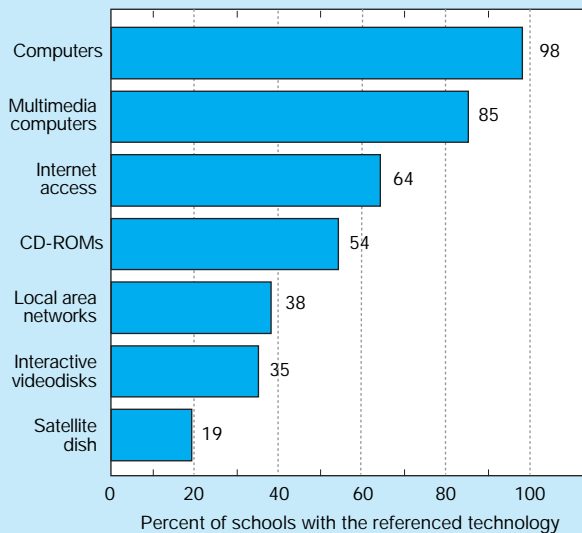
Figure 8-15.
Number of K-12 students per computer,
by state: 1995-96



SOURCE: Educational Testing Service, *Computers and Classrooms: The Status of Technology in US Schools, Policy Information Report* (Princeton: Educational Testing Service, Policy Information Center, 1997).

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Figure 8-16.
Diffusion of IT in U.S. public schools: 1996



NOTE: IT is information technologies.

SOURCE: Educational Testing Service, *Computers and Classrooms: The Status of Technology in US Schools, Policy Information Report* (Princeton: Educational Testing Service, Policy Information Center, 1997).

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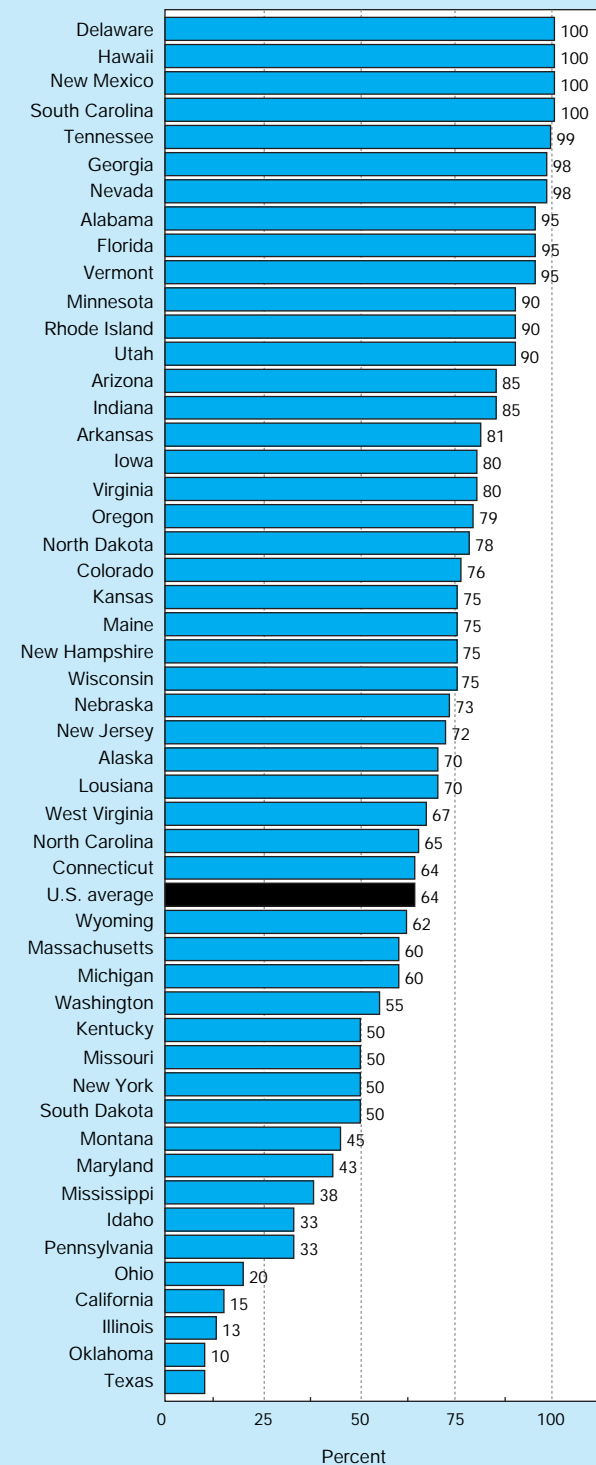
Text table 8-5.
Instructional use of computers in K-12 education: 1992
(Percentages)

Type of use	Total	Grade 5	Grade 8	Grade 11
Total student use	100	100	100	100
Academic subjects	51	58	44	43
Mathematics	15	18	12	7
English	13	17	10	7
Science	7	8	7	6
Social studies	7	9	6	3
Business education	4	3	3	10
Industrial arts	2	1	3	6
Fine arts	2	2	2	2
Foreign languages	1	–	1	2
Computer training	39	32	46	51
Word processing	14	12	16	17
Keyboarding	14	13	15	14
Programming	5	3	7	8
Spreadsheets	6	4	8	12
Recreational use	9	10	10	6
Other	1	1	1	–

SOURCE: U.S. Bureau of the Census, *Statistical Abstract of the United States 1996*, table 262 (Washington, DC: U.S. Government Printing Office, 1996); based on the Computers in Education Study conducted by the International Association for the Evaluation of Educational Achievement.

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Figure 8-17.
Percentage of K-12 schools with Internet access, by state: 1996



SOURCE: Educational Testing Service, *Computers and Classrooms: The Status of Technology in US Schools, Policy Information Report* (Princeton: Educational Testing Service, Policy Information Center, 1997).

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Impacts of IT on K-12 Student Learning

A keyword search of ERIC, the primary bibliometric database used for educational research, yields thousands of citations related to computer-assisted instruction and student achievement. The signal characteristic of this research is its seeming lack of comparability: studies range from anecdotal reports to formal experimental designs, many of which control for different sets of variables and include different types of computer use in different subject areas. Moreover, interest in the effects of computers on young people is not limited to learning and achievement. Concerns about the emotional and psychological effects of prolonged exposure to computing environments have also been raised. (See “Children, Computers, and Cyberspace.”)

One way of integrating disparate research is with “meta-analysis,” a statistical technique used in the field of educa-

tion and other disciplines.²⁸ Meta-analysis provides a way of standardizing the statistical results of quantitative research so that multiple studies can be compared in a reliable manner. About a dozen meta-analyses have been conducted on the effects of computer-based instruction, all of which find positive (though not necessarily large) learning effects. The magnitude of learning effects varies across a host of conditions, including type of instruction, subject matter, duration of the experimental treatment, and degree of teacher training. Detailed information on meta-analysis as an integrating methodology is presented here, as are two meta-analyses of the impacts of CBI on precollege learning. These studies illustrate the methodology of meta-analysis, the resulting metrics, and the interpretation of such metrics.

²⁸Detailed reviews of the meta-analytic technique may be found in Hittleman and Simon (1997); Kulik and Kulik (1991); Ryan (1991); McNeil and Nelson (1990); and Glass, McGaw, and Smith (1981).

Children, Computers, and Cyberspace

Education scholar Larry Cuban once remarked that “if the full influence, both positive and negative, of television watching on children continues to be debated three decades after its introduction, how can anyone assess the complexity of what happens to children using classroom computers?” (1994, p. 537).

The comparison to television is pertinent, since many of the concerns raised about children, computers, and the Internet are similar to those raised in the past for TV. Of particular concern is the psychological and emotional well-being of children. Cyberspace brings its own set of potential dangers to children, including cyberhate and cyberporn—forms of adult expression that children might not be able to handle.

The extent of the problem—the access by children to age-inappropriate materials on the Internet—is debated intensely. The ease with which children may access sexually explicit materials is disputed (see Gay 1996), but congressional testimony (U.S. Senate 1995) and case studies (Turkle 1995) reveal that young people can easily obtain graphic sexual photographs and engage in “netsex” on the Internet; one young teen also reported being electronically stalked by an adult who clearly knew she was a minor.

The primary legislative effort to protect children on the Internet was the Communications Decency Act of 1996, a law that made providing “indecent” material to minors over the Internet a crime. The act was declared unconstitutional by the Supreme Court in 1997 (*Reno v. American Civil Liberties Union*) for a variety of reasons, including the fact that indecent material has consistently been protected as a form of free speech in the United States. (The Supreme Court has historically made a distinction between

indecent and obscene material; obscenity is not protected under the First Amendment.) Limiting children’s access to inappropriate materials has now become a technological challenge, relying on such filtering software as Cyber Patrol™ and CYBERSitter™. Adult verification systems such as Adult Check™ also are becoming more common. Note that children’s vulnerability is not limited to sexually explicit materials; parental concerns have also been raised with regard to Internet violence, hate speech, deceptive advertising, “false front” Web sites, and exploitation of children’s privacy.

Concerns about core psychological processes—such as self-identity—have also been examined. Sherry Turkle, a behavioral scientist who studies the impact of early and prolonged use of computing environments on children, has uncovered patterns that suggest the computer culture is not benign. Computing and cyberspace may blur children’s ability to separate the living from the inanimate, contribute to escapism and emotional detachment, stunt the development of a sense of personal security, and create a hyper-fluid sense of identity (Turkle 1984 and 1995).

While there may be psychological benefits associated with computer-mediated reality (including greater empathy for those of different cultures, sex, or ethnicity; heightened adaptability; and a more flexible outlook on life), the “darker side” of the technology is nonetheless unsettling. Turkle raises the possibility that extensive interaction with cyberspace (especially through multi-user domains) may create individuals incapable of dealing with the messiness of reality, the needs of community building, and the demands of personal commitments (Turkle 1995).

Meta-Analysis

Meta-analysis is a method for combining the statistical results of research studies that test the same general hypothesis and use the same statistical measures. Meta-analysis related to CBI focuses primarily on the impact of computer usage on student learning, although other educational outcomes may be studied (such as attitudes toward computers, attitudes toward school subjects, and amount of time needed for instruction).

As discussed here, meta-analysis yields a standardized metric called an “effect size.” Effect size is a score that measures the difference in performance between experimental and control groups. For CBI, effect size is based on the performance of control and experimental groups on a common examination. As a metric, effect size is expressed as a proportion of standard deviation (a z-score) and has a percentile equivalent; it also controls for the influence of sample size.²⁹ The z-score reflects how much better (or worse) the experimental group performed on an exam relative to the mean of the control group. Examples of effect sizes and their interpretation are provided below in the discussion of specific meta-analytic research.

Meta-analysis is valuable for two key reasons. First, it allows researchers to cumulate and integrate the findings of multiple studies (particularly those that are small in size) into a single measure of outcome. Second, it estimates a specific magnitude for an independent variable’s impact. Other methods that aggregate diverse studies, such as “tallies” and “box scores,” indicate overall patterns and trends in research findings but do not estimate the degree of influence of one variable on another.

Meta-analysis has a number of potential weaknesses, however. First, biased or flawed studies, when cumulated, will generate biased or flawed meta-analysis. Second, for some types of meta-analysis, aggregative data can lead to “Simpson’s Paradox”—an outcome in which the statistics indicate a relationship opposite to what is actually occurring. Simpson’s Paradox is most likely to occur with the aggregation of categorical data, such as that of risk assessment (see Utts 1996). Third, the results of meta-analysis are point estimates; that is, they are single numeric values (z-scores) without reference to a confidence interval or some estimate of the precision of the estimates themselves. As a consequence, meta-analysis z-scores reflect a level of unmeasured uncertainty.

Meta-analysis therefore relies upon rigorous research designs to avoid potential pitfalls. Two factors affect the overall quality of a meta-analytic study (Hittleman and Simon 1997, and Utts 1996). One factor is the decision about what primary research to include in the synthesis. Ideally, only research that reflects experimental and quasi-experimental design should be used; target groups should contain large numbers (typically 20 or more units of observation); data on means, standard deviations, and sample sizes should be reported; and

²⁹Studies with small sample size tend to have large statistical variance, while large studies have smaller variance. Meta-analysis controls for variance and provides greater weight to the results of large studies, which tend to be more statistically robust.

methodologically flawed studies should be eliminated from the analysis. In this way, only the most rigorous studies are included for synthesis. Second, because meta-analysis must account for a large number of other factors that can potentially affect the dependent variable, coding of these additional factors must be particularly precise and consistent. As a consequence, the meta-analysis research design must contain provisions for checking intra- and/or inter-coder reliability. The two studies reported below conform to the general requirements for proper meta-analysis and avoid the most common pitfalls associated with this type of research.

Meta-Analyses of Computer-Based Instruction

In general, traditional literature reviews and box-score tallies of computer-based instruction research indicate positive effects. CBI appears to result in some degree of observable achievement effect most of the time, but not always. Meta-analyses try to quantify precisely the magnitude of these effects; over a dozen meta-analyses of CBI covering precollege and postsecondary education have been conducted.³⁰ Three observations are worth noting here.

- ♦ In their review of 11 meta-analyses, Niemiec and Walberg (1987) find evidence that effect sizes for high school and college tend to be smaller than for elementary school and students with special learning needs.
- ♦ There is systematic evidence that CBI effect sizes are higher in the published literature than in unpublished documents such as dissertations, conference papers, technical reports, and professional presentations. Meta-analyses must consequently include nonpublished research findings to avoid overly positive estimates of the impact of CBI on student learning.³¹ The two meta-analyses discussed in detail here (Kulik and Kulik 1991, and Ryan 1991) take care to include a variety of nonpublished literature in their syntheses.
- ♦ The meta-analyses conducted to date cover CBI only from the late 1960s to the mid- to late 1980s. Therefore, these studies do not reflect the substantial changes in computer hardware, educational software, teacher preparedness, and styles of computer-based teaching and learning that may have occurred in the 1990s.

Kulik and Kulik (1991) performed a meta-analysis on 254 studies conducted between 1966 and 1986. The CBI effectiveness studies included in the meta-analysis reflect (1) all levels of education—precollege and postsecondary, (2) controlled evaluations³² in real classroom settings, not laboratories; and (3) research free from a number of methodological

³⁰Niemiec and Walberg (1987) identify 11 such studies; more recent meta-analyses include Kulik and Kulik (1991), Ryan (1991), and McNeil and Nelson (1990).

³¹This is not necessarily problematic. Bibliometric databases in the field of education include dissertations, technical reports, and unpublished conference papers.

³²For example, two courses teach the same subject matter, but one course uses CBI (the experimental or treatment group) and one course uses conventional instruction (the control group). At the end of the treatment period, students are given the same test and test performance is compared.

flaws specified by the authors. Even though the studies themselves reflect controlled research designs, they often capture different contextual factors. As a consequence, Kulik and Kulik coded a large set of “control” variables that might affect learning outcomes, such as the type of computer application, the instructor, and course content. (See text table 8-6.)

Although the Kulik and Kulik study synthesized findings for several educational levels, many findings for K-12 CBI were reported separately. Two examples and interpretations of K-12 effect size from this study are presented here. In the first example, the overall effect size for 68 studies on computer-assisted instruction at the precollege level was 0.36. Because effect size is a standardized value based on the normal distribution and standard deviation, it can be interpreted as a z-score and converted to a percentile equivalent. A z-score of 0.36 is equivalent to the 64th percentile; students using CBI scored (on average) in the 64th percentile on measures of learning and achievement compared to the 50th percentile for students in a traditionally taught class.³³

³³Note that students in a conventionally taught course are the control group. Assuming a normal distribution of test scores, the average test score (the mean) of this group represents the 50th percentile: one-half of all students score above the mean, and one-half score below the mean. The z-score that corresponds to the mean of a normal distribution is zero, so the effect of CBI would be zero because it is not used in the control group.

Obviously, factors other than CBI could have influenced these learning outcomes. Of the nine major categories of variables that Kulik and Kulik evaluated as alternative predictors of effect size, four were statistically significant influences: the type of application, the duration of instruction, the year of research publication, and the publication status of the research.³⁴ Effect sizes were systematically higher for:

- ♦ computer-assisted instruction (as opposed to computer-managed or computer-enriched instruction),
- ♦ instruction periods of four weeks or less in duration,
- ♦ reports published before 1970, and
- ♦ published research.

These findings are somewhat suggestive, since they indicate that (1) some types of CBI may be more effective than others (at least given existing courseware), (2) learning effects may diminish when computers are used for long periods, (3) there may be “novelty” learning effects associated

³⁴Statistical significance means that the average response (e.g., test score) is distinctly different between the groups in question. Tests of statistical significance are based on probability theory.

Text table 8-6.

Typical study features accounted for in computer-based instruction meta-analyses

Kulik and Kulik	Ryan
Type of application (computer-assisted instruction, computer-managed instruction, computer-enriched instruction)	Student features (grade level, socioeconomic status, school type, school area, ability level)
Duration of instruction (four weeks or less, more than four weeks)	Computer hardware (computer make, color monitor, music and sound, synthesized speech, input devices)
Type of computer interaction (off-line, terminal with mainframe, microcomputer)	Software (subject area, source, type of application—e.g., drill and practice, simulation, tutorial)
Subject assignment to study groups (random, nonrandom quasi-experimental design)	Size of instructional unit
Instructor effects (same instructor for experimental and control groups, different instructors for experimental and control groups)	Physical setting (type of communication, type of room)
Test bias (commercial standardized test, locally developed test)	Duration of instruction (duration of treatment, length of sessions, frequency of sessions)
Course content (mathematics, science, social science, reading and language, combined subjects, vocational training, other)	Instructor features (professional level, hours of pretraining)
Year of report^a	Methodological features (subject assignment, instructor effects, test-author bias)
Source of study findings (e.g., technical report, dissertation, article, book, etc.)	Year of report^a
	Source of study findings (e.g., technical report, dissertation, article, book, etc.)

^aYear of report can be used as a proxy for the age, or “vintage,” of the computer equipment.

SOURCES: C.-L. Kulik and J.A. Kulik, “Effectiveness of Computer-Based Instruction: An Updated Analysis,” *Computers in Human Behavior*, Vol. 7 (1991): 75-94; and A. Ryan, “Meta-Analysis of Achievement Effects of Microcomputer Applications in Elementary Schools,” *Educational Administration Quarterly*, Vol. 27, No. 2 (May): 161-84.

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with computer use,³⁵ and (4) not all CBI has a demonstrable achievement effect.

As a second example of meta-analysis, effect sizes for specific academic subjects varied from 0.10 for science (54th percentile), 0.25 for reading and language (60th percentile), and 0.37 for mathematics (64th percentile). Although it may be tempting to conclude from these metrics that CBI is more effective for mathematics than other subjects, these subject matter differences in effect size were not statistically significant in the meta-analysis.

When presented as percentile equivalents or as fractions of a standard deviation, gains in computer-assisted instruction appear modest. Another way of interpreting meta-analysis effect size is as grade-equivalent scores, which provide a more concrete sense of impact (Ryan 1991). Glass, McGaw, and Smith (1981) report that in elementary school grade levels, the standard deviation on most achievement tests is the equivalent of one grade level. As a consequence, a 0.36 effect size, which is equivalent to 0.36 standard deviations, represents a gain of about 3 to 4 months of instruction, assuming the school year is about 9 to 10 months long. This indicates that about three to four months' more learning occurred than could generally be expected in a school year. However, because the Kulik and Kulik effect sizes reported above are for both elementary and secondary schools, they cannot be interpreted in grade-equivalent gains.

Ryan's (1991) meta-analysis of the effects of microcomputers on kindergarten through sixth grade achievement can be reported on a grade-equivalent basis. Her meta-analysis of 40 studies³⁶ conducted between 1984 and 1989 found an overall effect size of 0.309. Thus, the average K-6 student using a microcomputer as an instructional tool performed in the 62nd percentile on tests, compared to the 50th percentile for the average K-6 student who did not use a microcomputer. Ryan explains that

the effect size of .309 means that the effect of computer instruction is approximately one-third greater than the effect of control group instruction. In terms of grade-equivalent units, .309 can be interpreted as one third greater than the expected gain in a school year, approximately 3 months additional gain in [grade level]" (p. 171).

Ryan likewise evaluated several sets of variables other than CBI that may have had an impact on effect size. (See text table 8-6.) Of these variables, only the degree of teacher pretraining was statistically significant. In experimental groups where teachers had fewer than 10 hours of computer pretraining, the effect size of CBI was negligible and, in some instances, negative. In groups where teacher pretraining ex-

ceeded 10 hours, the effect size was 0.53, equivalent to one-half a school year gain, or 70th percentile performance. Ryan's findings reinforce other studies that identify the crucial role of teacher preparedness in effective CBI (U.S. OTA 1995 and PCAST 1997).

Computers and Alternative Instruction

Computer-based instruction can also be incorporated into enriched learning environments. Isolating the effects of computers in these alternative approaches to education is difficult, but the positive impacts of the full instructional package for several special projects merit note. One is the Higher Order Thinking Skills (HOTS) Program, an intervention program for economically disadvantaged students in the fourth through seventh grades. Students were taken from their traditional classrooms and taught through an innovative curriculum that integrated computer-assisted instruction, drama, and Socratic method. Students in the HOTS Program outperformed other disadvantaged students in a control group on all measures and had double the national average gains on standardized tests in reading and mathematics (Costa and Liebmann 1997). The Buddy Project in Indiana, in which students in some classrooms were given home computers, also reported highly positive results across a variety of skills. Similar results were reported for the Computers Helping Instruction and Learning Development in Florida, an elementary school program that emphasized student empowerment, teacher training and teamwork, and independent learning (ETS 1997). These studies suggest that the use of computers in enriched, nontraditional learning environments might achieve the fundamental changes in student learning that advocates of computer-based instruction desire.

IT and the Citizen

Access to information and proficiency with information technologies could potentially influence an individual's well-being. Employability and income are tied increasingly to computer training and literacy, and a home computer could enable families to change their work patterns through telecommuting. (See "Trends in Telecommuting.") Because of the rapidly expanding variety of services offered on the Internet and World Wide Web, information access might also play a growing role in medical care,³⁷ civic and political participation, lifelong learning, recreation and leisure activities, and personal finance. In short, information consumption, use of IT, and effective "knowledge management" could become increasingly instrumental to health, wealth, power, and overall quality of life.

The growing significance of information raises questions about the equity of access to information technologies. In addition, the steady growth of databases about individual citizens—and the power of IT to combine those data into

³⁵The higher effect sizes for studies published before 1970 are intriguing, and may reflect novelty impacts. Such effects result from the greater attention and effort an individual gives to a substantially new technology and not necessarily from any intrinsic contributions of the technology itself.

³⁶Ryan also had a precise set of stringent selection criteria, including the requirements that the study reflect experimental or quasi-experimental design, that the sample size be at least 40 students (a minimum of 20 students in the treatment and control groups), and that the treatment last eight weeks or longer.

³⁷Survey data indicate that people are increasingly using the World Wide Web for health-related information. See chapter 7, "The Use of Computer Technology in the United States."

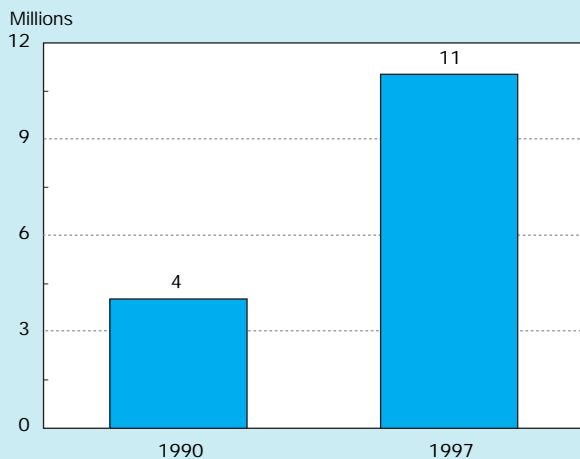
Trends in Telecommuting

Telecommuting is considered to be one of the more positive benefits of IT and networks. Working from home alleviates traffic congestion, accommodates family schedules, and enhances white-collar productivity. Telecommuting is promoted by such corporate giants as Motorola, AT&T, Sun Microsystems, IBM, Ernst and Young, and Hewlett Packard. Corporate telecommuters work almost half of their work week at home (about 19 hours).

The number of individuals who reported working as telecommuters in 1997 was 11 million, just under 10 percent of the U.S. labor force. (See figure 8-18.) The total is growing rapidly, however, at about 15 percent a year. Some analysts estimate that at least 40 percent of today's workers could be telecommuters at least part of the time. For these statistics and others, see *Telecommute America* (1997).

Figure 8-18.

Number of telecommuters in the United States



SOURCE: Telecommute America, "News Release July 2, 1997"
<<<http://www.att.com/press/0767/970702.bsa.html#facts>>>.

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highly revealing portraits about an individual—presents the possibility that rather than enhance personal liberty and well-being, information will instead tyrannize the private citizen. Although scholars have as yet found little evidence that the Internet changes the dynamics of democratic governance and discourse (see King and Kraemer 1997), the volume of data collected on private individuals without their consent has increased. This section therefore examines the impacts of IT on two dimensions of civil life: equity of opportunity and personal privacy. Note, however, that these are only two of the many ways in which IT may affect individuals. Other issues of interest include the role of information for per-

sonal empowerment and quality of life, the impact of IT on government services and public access to government services, and the potential impact of IT on human cognition and thinking processes.

Equity Issues

Equality of opportunity is a hallmark of U.S. political culture and reflects a national commitment to minimize structural barriers to personal achievement.³⁸ With respect to education and IT, equity is of particular concern not only because of the importance of training an adequately prepared workforce, but also because (as reviewed earlier) use of IT can affect children's learning ability. Personal and household access to computers and the Internet facilitates distance education, access to health information and government services, and job searches in classified ads. Inequality of information access and IT literacy could aggravate existing race, ethnic, and class divisions in the United States; conversely, equality of information access and information skills could help integrate ethnic groups, the poor, and rural communities into the economic and political systems.

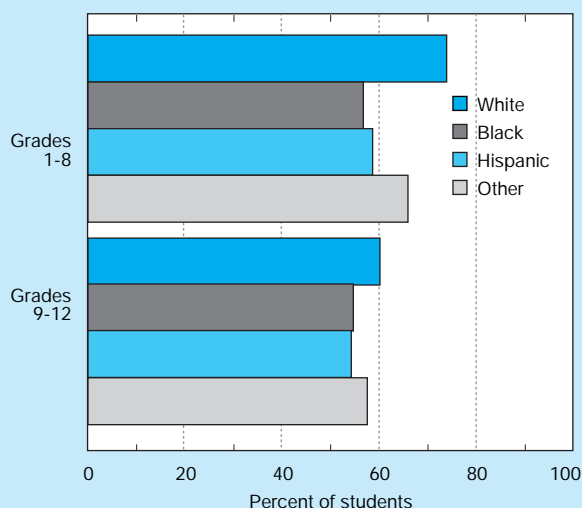
Educational Inequities

Diffusion data indicate that pronounced educational inequalities in access to IT exist—key (and interrelated) determinants of access are income, race, and ethnicity. Schools with white, affluent, and suburban students have the greatest levels of IT adoption; schools with poor and minority students have considerably lower IT adoption rates. Inequities in access to IT may be particularly difficult to overcome when considered in the context of major inequalities in school facilities, resources, teacher training, and curriculum among ethnic minorities and the poor (Kozol 1991).

Differences exist in student computer use by race or ethnic group and grade level. (See figure 8-19.) At the elementary school level (grades 1-8), inequalities are particularly pronounced. While nearly three-quarters of all white elementary school children used computers at school in 1993, fewer than two-thirds of black and Hispanic children did. Because elementary school use of computers is particularly focused on drill-and-practice activities in mathematics and reading, the data suggest that minority children are getting less computer-reinforced training in basic skills than their white counterparts. Although inequalities in computer use diminish by high school—about 55 percent of black and Hispanic teenagers use computers at school, compared to 60 percent of white teens—variations in the content of that use are notable. For example, college-bound minority students get less experience in all major areas of computing applications than college-bound whites except data processing and computer programming.

³⁸Structural barriers may reflect deliberate discrimination (such as hiring and promotion practices) as well as nondiscriminatory but excessively inequitable treatment (such as variations in school funding within a school district). In some instances, equal opportunity may also involve proactive efforts to correct inequalities among disadvantaged groups.

Figure 8-19.
Student use of computers at school, by grade level and race/ethnicity: 1993



See appendix table 8-8. *Science & Engineering Indicators – 1998*

(See figure 8-20.) Female students get less experience than males in all applications except word processing and use in English courses.

These inequities in computer use at the elementary and high school levels could be the result of curriculum and teacher training as well as in-school access. As discussed earlier, research shows that use of computing resources depends on a teacher's training and ability to integrate computer-based instruction into the existing curriculum. One government report finds some evidence of differences in computer training among teachers of different ethnicity and socioeconomic status (PCAST 1997); however, diffusion data suggest that differences in students' school use of IT depend upon the availability of the equipment itself. Citing data from Quality Education Data, Inc., the Educational Testing Service (1997) notes that schools with a minority population of less than 25 percent have student-to-computer ratios of about 10 to 1, while schools with 90 percent or more minority students have ratios of 17.4 to 1. Similarly, the National Center for Education Statistics (1997) reports that schools with 50 percent or more minority students have Internet access in only 5 percent of their instructional classrooms, compared to 18 percent in schools with minority populations of 20 percent or less.

As with race and ethnicity, income is associated with student computer use. In 1993, three-quarters of all elementary school children from households with incomes greater than \$50,000 used a computer at school, compared to two-thirds (or below) for children from households with incomes lower than \$20,000. (See figure 8-21.) Internet access is similarly inequitable. Schools that have the largest proportion of economically disadvantaged students have less than one-half the level of Internet access as more affluent schools. (See figure 8-22 and

figure 1-17 in chapter 1.) In short, schools with large minority and poor populations have less access to all information technologies, including multimedia computers, cable TV, Internet hook-ups, interactive videodisk, CD-ROMs, and satellite connections (ETS 1997).

Household Inequities

Inequality of access to information technologies applies to adults as well as children. In 1993, about a third more whites used computers at work than blacks, and over a half more whites used computers at work than Hispanics. (See figure 8-23.) The disparity is even more pronounced regarding home use. The percentage of whites with a computer at home is twice that of blacks or Hispanics.³⁹

There appears to be a distinct class of "IT-disadvantaged" citizens. Adults who have not graduated from high school have one-fourth the level of ownership of home computers compared to those individuals with graduate or professional degrees. (See figure 8-24.) And the lowest income groups report one-ninth the level of computer ownership compared to individuals in the highest income brackets. (See figure 8-25.) Children share in this household inequity; more than 10 times as many of the most well-off children use computers at home as do the poorest students—more than 60 percent compared to about 5 percent. (See appendix table 8-8.)

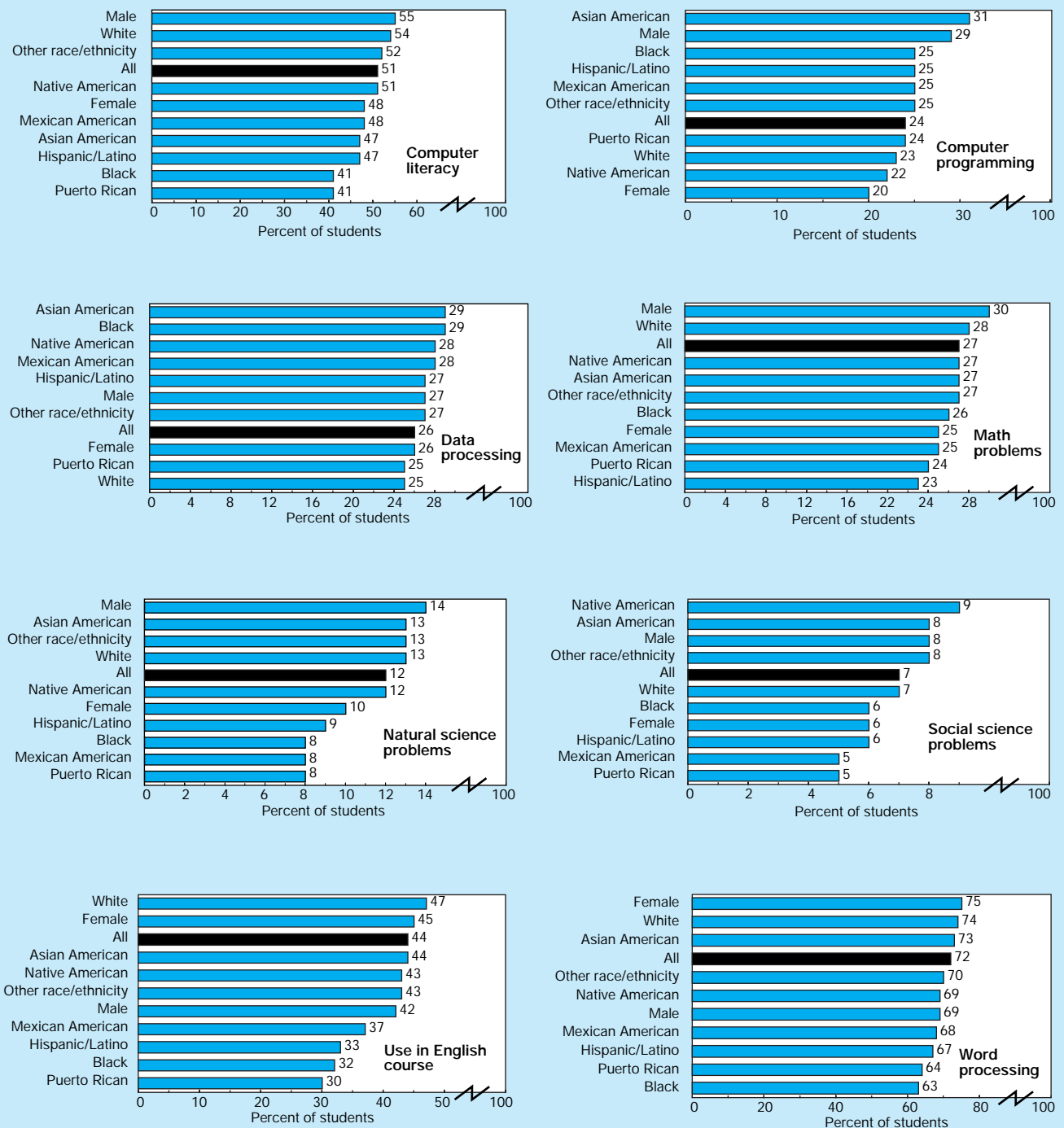
Geographic data shed light on the informationally disadvantaged. The National Telecommunications and Information Administration (NTIA) finds that "in essence, information 'have nots' are disproportionately found in this country's rural areas *and* its central cities, [however] no situation compares with the plight of the rural poor" (NTIA 1995). Only 5 percent of rural households with annual incomes of less than \$10,000 have computers—the lowest rate of ownership for any group. (See figure 8-26.) Unfortunately, these households cannot compensate for their lack of information access at home by using public libraries. As noted earlier, fewer than one-third of the libraries that serve communities of less than 5,000 have Internet access, compared to 93 percent of the libraries in metropolitan areas of 100,000 or more.

The irony of limited access by the poor, the least educated, and rural communities to information technologies is that when these groups gain access to IT and networks, they use the technology for self-advancement. NTIA reports that:

Many of the groups that are the most disadvantaged in terms of absolute computer and modem penetration are the most enthusiastic users of on-line services that facilitate economic uplift and empowerment. [Census survey data reveal that] low-income, minority, young, and less-educated computer households in rural areas and central cities appear to be likely to engage actively in searching classified ads for employment, taking educational classes, and accessing government reports, on-line via modem (1995, p. 3).

³⁹Note that white, black, and Hispanic computer owners *do* tend to have comparable technological access to networks: there are no meaningful differences among racial and ethnic groups in terms of whether their computers have modems. See NTIA (1995).

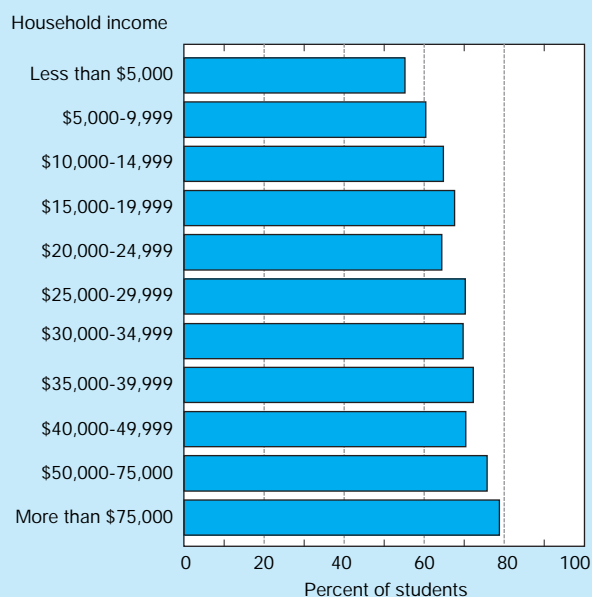
Figure 8-20.

Computer-related experience of college-bound seniors, by sex, race/ethnicity, and computing applications: 1996

NOTE: Data are for college-bound seniors who took the SAT.

SOURCE: Educational Testing Service, *Computers and Classrooms: The Status of Technology in US Schools, Policy Information Report* (Princeton: Educational Testing Service, Policy Information Center, 1997); data from The College Board.

Figure 8-21.
Student use of computers at school, grades 1-8,
by level of household income: 1993



See appendix table 8-8. *Science & Engineering Indicators – 1998*

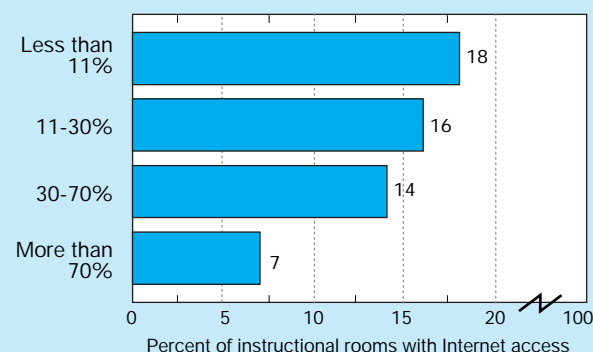
Bier et al. (1996) found similar results in a well-structured ethnographic study of home Internet use by six low-income families in Florida. These families were provided with home computers and Internet access to “see what families designated as ‘informationally disadvantaged’ would actually do on-line given unrestricted home Internet access” (p. 1). Families in the study used their computers and the Internet to acquire health information, create network support groups, search for jobs, and do school work.⁴⁰ Individuals reported growth in their self-esteem, better grades, more effective communications with physicians, and closer relationships with their children. They also spoke of their fear of losing the technology because of the temporary nature of the study. As the authors summarize:

We did not anticipate the profound ways in which our participants’ interactions with the technology and the relationships it made possible would change them, their sense of identity, and the content of their lives. While these changes were perceived as positive by the participants, our dilemma arose when participants began to express their growing fear of the time when they would be expected to return the borrowed equipment...According to use of human subjects research codes we met our ethical responsibility to the participants by clearly delineating the temporary nature of the resources provided...However, we have come to feel that adherence to these standard ethical requirements is insufficient to adequately address

⁴⁰The authors state that “participants made use of virtual hospitals, medical dictionaries, and physician desk references. They joined support groups, visited international zoos, investigated scholarships, and made local transportation arrangements. They investigated appliances, looked at employment listings, and kept up with the local calendar of events” (Bier et al. 1996, p. 3).

Figure 8-22.
Level of Internet access in schools by student
body income level: 1996

Percent of students eligible for free or reduced-price school lunch



SOURCE: National Center for Education Statistics, “Advanced Telecommunications in U.S. Public Elementary and Secondary Schools, Fall 1996,” *Statistics in Brief*, NCES 97-944 (Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement, 1997).

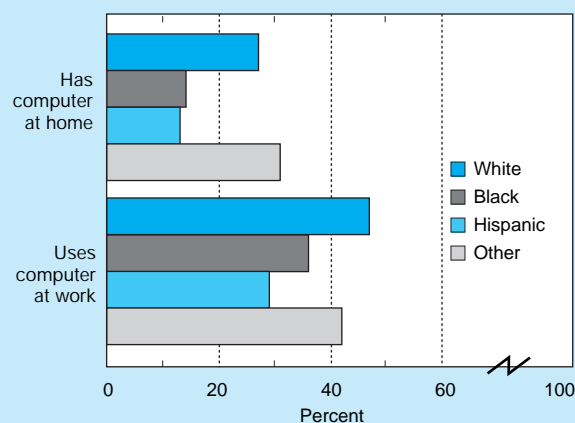
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the principle of reciprocity in our relationships...In this study it became important...to actively support the positive potential awakened in the participants (p. 9).

Privacy Issues

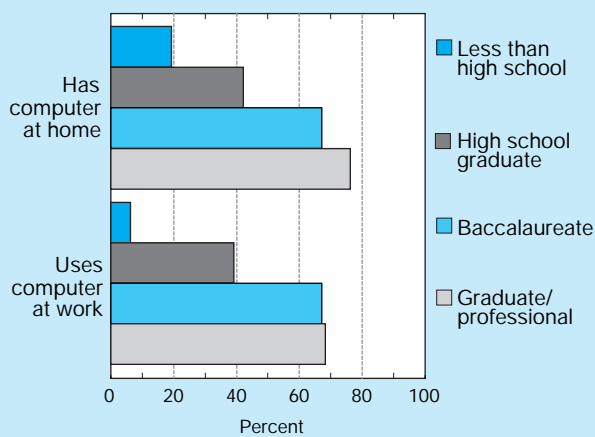
IT offers extraordinary potential for collecting and reporting detailed information about individuals that many would consider to be private. Information on medical histories, credit records, shopping habits, spending practices, income levels, magazine subscriptions, video rentals, vacation preferences, and

Figure 8-23.
Proportion of adults who use computers
at home and at work, by race/ethnicity: 1993



See appendix table 8-9. *Science & Engineering Indicators – 1998*

Figure 8-24.
Proportion of adults who use computers at home
and at work, by level of formal education: 1997



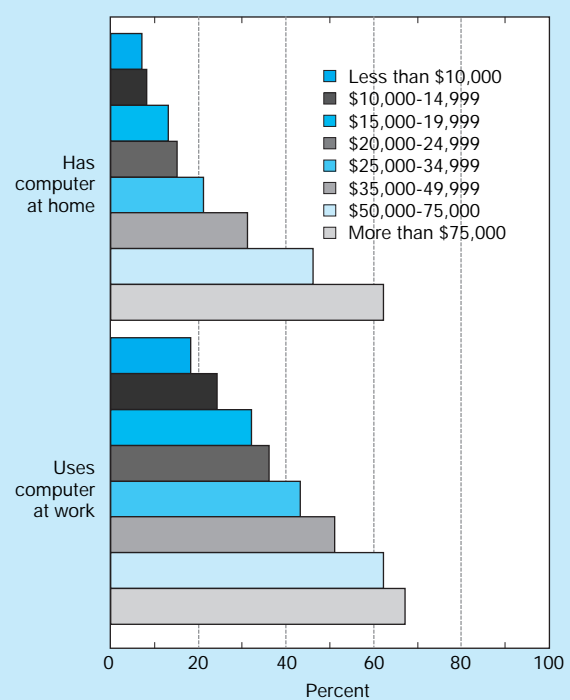
See appendix table 7-26. *Science & Engineering Indicators – 1998*

even coupon usage is routinely collected by commercial enterprises and stored in databases. These databases are, in turn, sold, bought, and “overlayed” into detailed electronic files on millions of individuals. With no more information than a name, address, phone number, or birthdate, a persistent “data miner” can compile a dossier with detail and scope that would shock most individuals. The proliferation and commercialization of personal data and information—and the fact that it is happening without the consent of the individual—has been well-documented (Smith 1994, Kahin and Nesson 1997, Regan 1995, Cavoukian and Tapscott 1997, and Culnan 1991). Other IT-related privacy issues include (but are not limited to) surveillance in the workplace (e.g., reading employees’ e-mail and listening to their telephone calls) and tracking a person’s Internet activities through an electronic tracer known as a “cookie.”

Not surprisingly, Americans’ concerns about protecting the privacy of their personal information and communications have been rising steadily for the past two decades. Concerns are sufficiently intense that more than a dozen pieces of related legislation have been passed since the 1970s (see Regan 1995 for a review). In addition, in 1994, Wisconsin became the first state in the country to establish an Office of the Privacy Advocate for its citizens, a bureau that actively promotes the protection of “personally identifiable” information.

Empirical measures of the proliferation of private information are not available. In addition, it is difficult to establish objective measures of violations of privacy, since privacy represents both values and psychological states. (In other words, violations of privacy are largely in the eye of the beholder.) If legal criteria are used—such as those of the 1974 Privacy Act, which essentially states that data cannot be collected on individuals without their permission—then we would be forced to conclude that violations of privacy are in fact commonplace.

Figure 8-25.
Proportion of adults who use computers at home
and at work, by income level: 1993



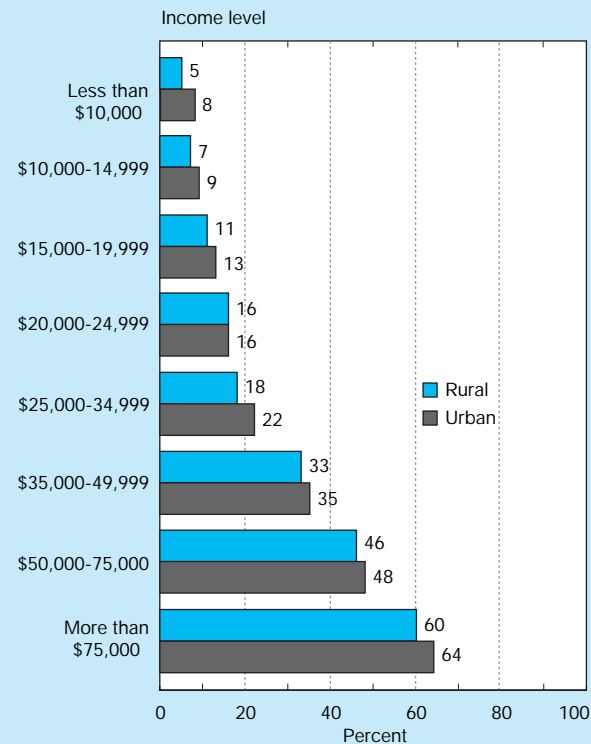
See appendix table 8-9. *Science & Engineering Indicators – 1998*

Easier to measure is a society’s collective sense about privacy and its safeguards. A variety of public opinion polls regarding privacy have been administered over the past 15 years, and they document a public concern over privacy that is growing in scope and intensity. By the mid-1990s, more people registered stronger concerns about protecting their privacy than at any other time. For example, the 1996 Equifax/Harris Consumer Privacy Survey found that 65 percent of those polled reported that protecting the privacy of consumer information was very important to them—an increase of 4 percentage points over the previous year (Equifax 1997).⁴¹ Medical privacy appears to be of particular concern (NRC 1997). In 1993, 96 percent of those surveyed believed that “federal legislation should designate all personal medical information as ‘sensitive’ and impose penalties for unauthorized disclosure.”⁴² Confidence in controls on information marketing is not strong, however. In 1993, nearly half of all respondents to the Equifax/Harris survey indicated that they agreed strongly with the statement that “consumers have lost all control over how personal information about them is

⁴¹The wording of the Equifax/Harris polls has changed over time, making direct comparisons across multiple years difficult. Analysts do, however, conclude that the trend in public opinion is distinctly toward greater and more intense concerns over violations of privacy (Regan 1995, and Cavoukian and Tapscott 1997).

⁴²Based on the 1993 Equifax/Harris Health Information Privacy Survey. See EPIC (1997).

Figure 8-26.
Percentage of U.S. households with a computer,
by income level and geographic location: 1994



NOTE: "Rural" reflects populations of less than 2,500 persons; "urban" reflects populations of more than 2,500 persons.

SOURCE: National Telecommunications and Information Administration, *Falling Through the Net: A Survey of the "Have Nots" in Rural and Urban America*, <<<http://www.ntia.doc.gov/ntiahome/fallingthru.html>>> (August 1997); table can be accessed at <<<http://www.ntia.doc.gov/ntiahome/tables.html>>>. Data are based on the U.S. Bureau of the Census, Current Population Survey, November 1994.

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circulated and used by companies," a response 27 percent higher than that reported just two years previously (Regan 1995). In addition, 60 percent of those surveyed in an American Civil Liberties Union poll believe that their health insurance data are being accessed by others for secondary uses (EPIC 1997).

Americans strongly believe in their right to information privacy. Ninety-three percent of respondents in a 1991 Time-CNN poll believed that "companies that sell information to others should be required by law to ask permission from individuals before making the information available." The vast majority of people believe that companies should be prohibited from selling information about household income (90 percent), bill-paying history (86 percent), and product purchases (68 percent) (EPIC 1996). With respect to Internet use, the 1996 Georgia Tech Fifth World Wide Web Poll revealed that on-line Web users almost unanimously valued the ability to visit Web sites anonymously (rating this item as 4.6 on a scale of 5), and strongly opposed the right of site providers to sell information about their users to other companies (rating the right to sell at 1.7 on a scale of 5) (EPIC 1996).

Conclusion

The Need for IT Metrics

Metrics are a form of information and are ideally developed to answer specific sorts of questions. Which measures a society collects and analyzes about the effects of a technology depends largely upon what it wants to know, and we would not expect that all societies necessarily want to know the same things. The metrics and analyses presented here are based on four central questions:

- ♦ How extensively is IT embedded in American society?
- ♦ How is IT being used for business, educational, and other needs?
- ♦ What are the positive consequences of this use?
- ♦ What are the warning signals about the negative consequences of this use?

Available metrics exhibit considerable weaknesses in their ability to answer the above questions. The single most important obstacle to effective data collection is the lack of standardized definitions of IT, and the exclusion of important costs associated with IT use. For example, in some economic studies, IT reflects only computers, while in others it captures computers and telecommunications hardware. Research shows that IT support personnel and training expenses are significant elements of the cost and effective use of IT, but that these expenses are not always included in research studies or data collection. To fully capture the extent of the technology, IT should be defined as computers and telecommunications equipment. In addition, IT-associated costs should be included when collecting expenditure data on IT. Key associated costs include software, personnel expenses for IT support staff (e.g., network administrators), and training expenses for individuals who use the technology. One major obstacle to more effective data collection is the lack of appropriate budgeting and accounting reporting systems at the organizational level. Another is that IT itself continues to change rapidly.

A further weakness is the relative absence of systematic information on how IT is actually being used. IT is a means to an end—principally information processing. A real appreciation for the impacts and consequences of IT requires understanding what information it allows us to collect, access, and process. The presence of the hardware itself does not tell us to what ends it is put, and it is the actual use of the technology that determines its effects. Systematic surveys of IT applications are thus in order. For example, time-on-task audits would reveal how individuals actually use computers and networks at their office, school, or home; analytical questions about the impacts of specific IT activities would develop from patterns of real use. Similarly, diffusion estimates for specific types of applications (such as CAD-CAM, electronic data interchange, inventory management systems, and business management systems) could narrow down and help identify impact-related questions. Systematic knowledge

Text table 8-7.
Viable information technologies metrics

Metric	Source of data	Comments
IT investments in industry (diffusion indicator)	U.S. Bureau of Economic Analysis	Investments in IT disaggregated by type of technology. Reported as an annual investment as well as capital stock at the individual industry level.
IT hardware in K-12 schools (diffusion indicator)	Quality Education Data Inc., Denver, CO	Investments in several types of IT (computers, satellites, CD-ROMs, etc.) by school and location. Contains detailed data about school demographics.
K-12 Internet access (diffusion indicator)	National Center for Education Statistics	Extent of Internet access by type of school and location; contains detailed data about school demographics.
Library Internet access	American Library Association	Extent of Internet access by libraries (public and academic). Detailed data on size of community library services.
Individual perceptions of privacy (impact indicator)	Equifax/Harris Survey	Time-series data on public perceptions about violations of information privacy and rights to information privacy.
Patterns of individual use of the World Wide Web (usage indicator)	Georgia Tech Internet Survey	How individuals use the Internet and values about access to information.

IT = information technologies

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about the degree of importance of different uses and applications of IT is missing.

Recommendations for IT Metrics

Diffusion indicators for IT are relatively abundant and analytically useful. Several good data series exist that could be compiled into an ongoing set of diffusion metrics. These indicators are presented in text table 8-7, and include IT investments and stocks by industry and IT in K-12 schools. A lack of diffusion/IT intensity metrics is notable for both the education and economic sectors with respect to IT-associated costs—personnel, software, and training. These IT expenses are emerging in the research as significant determinants of IT effectiveness, and need to be tracked on a systematic basis. The most striking lack of data relates to distance education: by definition, this is learning that takes place through the use of information technologies, and there are simply no reliable metrics on the scope and growth of this unique educational practice.

Impact measures for the economy are problematic, primarily because of the difficulty in measuring economic output for many of the service sectors. One alternative to this dilemma is to select a representative set of sectors—or those that are the most economically significant—and develop a set of impact metrics unique to each. The research evidence

suggests that IT impacts are highly firm- and industry-specific; it is unlikely that a single measure could capture the economic benefits of IT for all types of enterprises. Three potential measures—as illustrated by the banking industry—are those that reflect the volume of transactions processing, human versus electronic transaction costs for key types of transactions, and processing times for key transactions.

Impact assessments for IT and learning are complicated by a more severe measurement issue, which is the need to collect data through observational studies or controlled experiments. Meta-analysis suggests that computer-based instruction generates real learning impacts, but more rigorous and comprehensive studies need to be conducted. A large-scale controlled study would be one way to avoid the statistical dilemmas of small classroom experiments.

Finally, IT clearly raises quality-of-life issues for the individual citizen. Occupational injury, psychological stress, and violations of privacy are clearly potential dangers of the widespread use of information technologies in the workplace and in information-intensive industries. Consistent tracking of the hazards to the individual represented by extensive use of IT is in order. Because IT also can clearly enhance quality of life, inequity in IT access could create more social stratification in the United States. Ongoing monitoring of equity indicators is critical as the significance of IT to employment, health, and well-being grows.

References

- Aiello, J., ed. 1993. "Computer-Based Work Monitoring: Electronic Surveillance and Its Effects." Special issue on computer monitoring. *Journal of Applied Social Psychology* 23, No. 7: 499-507.
- Alberts, D.S., and D.S. Papp, eds. 1997. *The Information Age: An Anthology on Its Impact and Consequences*. Available from <<<http://www.ndu.edu/inss/books/Anthology1/part1.html>>>.
- Allen, T., and M.S. Morton, eds. 1994. *Information Technology and the Corporation of the 1990s*. New York: Oxford University Press.
- Alpar, P., and M. Kim. 1991. "A Microeconomic Approach to the Measurement of Information Technology Value." *Journal of Management Information Systems* 7, No. 2: 55-69.
- American Library Association (ALA). 1996. "How Many Libraries Are on the Internet?" LARC Fact Sheet No. 26. Available from <<<http://www.ala.org/library/fact26.html>>>.
- Attewell, P., and J. Rule. 1994. "Computing and Organizations: What We Know and What We Don't Know." In C. Huff and T. Finholt, eds., *Social Issues in Computing*. New York: McGraw-Hill.
- Autor, D., L. Katz, and A. Krueger. 1997. "Computing Inequality: Have Computers Changed the Labor Market?" NBER Working Paper No. 5956. Cambridge, MA: National Bureau of Economic Research.
- Baily, M.N., and A.K. Chakrabarti. 1988. *Innovation and the Productivity Crisis*. Washington, DC: Brookings Institution.
- Banker, R.D., and R.J. Kauffman. 1988. "Strategic Contributions of Information Technology: An Empirical Study of ATM Networks." In *Proceedings of the Ninth International Conference on Information Systems*. Minneapolis.
- Banker, R.D., R.J. Kauffman, and M.A. Mahmood. 1993. *Strategic Information Technology Management: Perspectives on Organizational Growth and Competitive Advantage*. Harrisburg, PA: Idea Group Publishing.
- Bender, D.H. 1986. "Financial Impact of Information Processing." *Journal of Management Information Systems* 3, No. 2: 22-32.
- Benjamin, R. et al. 1984. "Information Technology: A Strategic Opportunity." *Sloan Management Review* (Spring): 3-10.
- Berman, E., J. Bound, and Z. Griliches. 1994. "Changes in the Demand for Skilled Labor Within U.S. Manufacturing: Evidence From the Annual Survey of Manufacturers." *The Quarterly Journal of Economics* (May): 367-98.
- Berndt, E., and C. Morrison. 1995. "High-Tech Capital Formation and Economic Performance in U.S. Manufacturing Industries: An Exploratory Analysis." *Journal of Econometrics* 65: 9-43.
- Bier, M. et al. 1996. "Personal Empowerment in the Study of Home Internet Use by Low-Income Families." *Journal of Computing in Education* 28, No. 5.
- Bradley, S.P., J.A. Hausman, and R.L. Nolan. 1993. *Globalization, Technology, and Competition: The Fusion of Computers and Telecommunications in the 1990s*. Boston: Harvard Business School Press.
- Brand, H., and J. Duke. 1982. "Productivity in Commercial Banking: Computers Spur the Advance." *Monthly Labor Review* (December): 19-27.
- Bresnahan, T. 1997. "Computerization and Wage Dispersion: An Analytical Reinterpretation." Paper prepared for the National Bureau of Economic Research, Summer Institute, August. Cambridge, MA: National Bureau of Economic Research.
- . 1986. "Measuring the Spillovers From Technical Advance: Mainframe Computers in Financial Services." *American Economic Review* 76, No. 4: 742-55.
- Brynjolfsson, E. 1993. "The Productivity Paradox of Information Technology: Review and Assessment." *Communications of the ACM* (December). Available from <<<http://ccs.mit.edu/CCSWP130/CCSWP130.html>>>.
- Brynjolfsson, E., and L. Hitt. 1995. "Information Technology as a Factor of Production: The Role of Differences Among Firms." *Economics of Innovation and New Technology* 3: 183-19.
- . 1996. "Paradox Lost? Firm-Level Evidence on the Returns to Information Systems Spending." *Management Science* 42, No 4: 541-58.
- Brynjolfsson, E., and S. Yang. 1996. "Information Technology and Productivity: A Review of the Literature." *Advances in Computers* 43: 179-214.
- Byrne, N. 1996. "Finance's Info-Tech Revolution—Special Report." *Business Week* (October 28): 129-38.
- Castells, M. 1996. *The Rise of the Network Society*. Cambridge, MA: Basil Blackwell.
- Cavoukian, A., and D. Tapscott. 1997. *Who Knows: Safeguarding Your Privacy in a Networked World*. New York: McGraw-Hill.
- Cerf, V.G. 1997. "Computer Networking: Global Infrastructure for the 21st Century." In Computing Research Association, *Computing Research: Driving Information Technology and the Information Industry Forward*. Available from <<<http://www.cs.washington.edu/homes/lazowska/cra/>>>.
- The Children's Partnership. 1996. *Where We Stand: May 1996*. Update to the report *America's Children and the Information Superhighway*. Available from <<<http://www.childrenspartnership.org/americaschild/stand.html>>>.
- Colwell, R. 1996. "Global Climate and Infectious Disease: The Cholera Paradigm." *Science* 274 (December 20): 2025-31.
- Costa, A., and R. Liebmann, eds. 1997. *Supporting the Spirit of Learning: When Process Is Content*. Thousand Oaks, CA: Corwin Press.
- Cron, W.L., and M.G. Sobol. 1983. "The Relationship Between Computerization and Performance: A Strategy for Maximizing the Benefits of Computerization." *Information and Management* 6: 171-81.
- Cuban, L. 1994. "The Promise of the Computer." In C. Huff and T. Finholt, eds., *Social Issues in Computing*. New York: McGraw-Hill.

- Culnan, M. 1991. "The Lessons of the Lotus Market Place: Implications for Consumer Privacy in the 1990's." Available from School of Business Administration, Georgetown University, <<<http://www.cpsr.org/dox/conferences/cfp91/culnan.html>>>.
- Curley, K., and P. Pyburn. 1982. "Intellectual Technologies: The Key to Improving White-Collar Productivity." *Sloan Management Review* (Fall): 31-39.
- Cyert, R., and D. Mowery, eds. 1987. *Technology and Employment: Innovation and Growth in the US Economy*. Washington, DC: National Academy Press.
- Danziger, J.N., and K.L. Kraemer. 1986. *People and Computers: The Impacts of Computing on End Users in Organizations*. New York: Columbia University Press.
- David, P.A. 1989. *Computer and Dynamo: The Modern Productivity Paradox in a Not-Too-Distant Mirror*. Stanford, CA: Stanford University, Center for Economic Policy Research.
- Denison, E. 1985. *Trends in American Economic Growth, 1929-1982*. Washington, DC: Brookings Institution.
- Eason, K. 1988. *Information Technology and Organizational Change*. New York: Taylor and Francis.
- Educational Testing Service (ETS). 1997. *Computers and Classrooms: The Status of Technology in US Schools, Policy Information Report*. Princeton: Educational Testing Service, Policy Information Center.
- Electronic Privacy Information Center (EPIC). 1996. "Who Owns Personal Information? Anatomy of a Privacy Case." Available from <<http://www.epic.org/privacy/junk_mail/public.html>>.
- . 1997. "Medical Privacy Public Opinion Polls." Available from <<<http://www.epic.org/privacy/medical/polls.html>>>.
- Equifax. 1997. "1996 Equifax/Harris Consumer Privacy Survey." Available from <<<http://www.equifax.com/consumer/parchive/svry96/docs/intro.html>>>.
- Finarelli, M.G. n.d. "GLOBE: A Worldwide Environmental Science and Education Partnership." Washington, DC: The GLOBE Program. Available from <<<http://www.globe.gov>>>; related student data from <<<http://www.globe.fsl.noaa.gov>>>.
- Forester, T. 1989. *Computers in the Human Context: Information Technology, Productivity, and People*. Cambridge, MA: MIT Press.
- Franke, R.H. 1989. "Technological Revolutions and Productivity Decline: The Case of U.S. Banks." In T. Forester, ed., *Computers in the Human Context: Information Technology, Productivity, and People*. Cambridge, MA: MIT Press.
- Freeman, C., L. Soete, and U. Efendioglu. 1995. "Diffusion and the Employment Effects of Information and Communication Technology." *International Labor Review* 134, Nos. 4-5: 587-603.
- Freeman, L. 1996. "Job Creation and the Emerging Home Computer Market." *Monthly Labor Review* (August): 46-55.
- Friedlander, A. 1997. *Infrastructure: The Utility of Past as Prologue*. Reston, VA: Corporation for National Research Initiatives.
- Gay, M.K. 1996. *The New Information Revolution*. Santa Barbara, CA: ABC-CLIO.
- Glass, G.V., B. McGaw, and M.L. Smith. 1981. *Meta-Analysis in Research*. Beverly Hills, CA: Sage Publications.
- Goodman, W.C. 1996. "The Software and Engineering Industries: Threatened by Technological Change?" *Monthly Labor Review* (August): 37-45.
- Graham, J. 1976. *Making Computers Pay*. New York: John Wiley and Sons.
- Grant, R.A., C. Higgins, and R. Irving. 1994. "Computerized Performance Monitors: Are They Costing You Customers?" In C. Huff and T. Finholt, eds., *Social Issues in Computing*. New York: McGraw-Hill.
- Griliches, Z. 1997. "Comment on Sichel." *The Review of Economics and Statistics* (August): 371.
- Harris, S., and J. Katz. 1991. "Organizational Performance and Information Technology Investment Intensity in the Insurance Industry." *Organization Science*, No. 2: 263-96.
- Herring, T. 1996. "The Global Positioning System." *Scientific American* (February): 44-50.
- Hittleman, D.R., and A.J. Simon (1997). *Interpreting Educational Research: An Introduction for Consumers of Research*, 2nd ed. Englewood Cliffs, New Jersey: Prentice Hall.
- Howell, D. 1997. "Institutional Failure and the American Worker: The Collapse of Low-Skill Wages." *Public Policy Brief*. Croton-on-Hudson, NY: Bard College, Jerome Levy Institute.
- Howell, D., and E. Wolff. 1993. *Changes in the Information-Intensity of the U.S. Workplace Since 1950: Has Information Technology Made a Difference?* Monograph R.R. #93-08. New York University, C.V. Starr Center for Applied Economics.
- Huff, C., and T. Finholt, eds. 1994. *Social Issues in Computing*. New York: McGraw-Hill.
- International Association for the Evaluation of Educational Achievement (IEA). n.d. "Computers in Education Study." Available from <<<http://uttou2.to.utwente.nl/comped/fr2/contents.htm>>>.
- International Data Corporation (IDC). 1997. "New Priorities and Technologies for the Year Ahead." Available from <<<http://www.idcresearch.com/BS97/111.htm>>>.
- Jorgenson, D., and K. Stiroh. 1995. "Computers and Growth." *Economics of Innovation and New Technology* 3: 295-316.
- Kahin, B., and C. Nesson. 1997. *Borders in Cyberspace*. Cambridge, MA: MIT Press.
- Katz, E.R., G. Tate, and W.A. Weimer. 1995. *Survey of Telematics for Education and Training: United States, Canada, and Australia. Vol. 2: United States*. Report by the European Association of Distance Teaching Universities for the DGXIII of the European Commission.
- Keen, P. 1995. *Every Manager's Guide to Information Technology*. 2nd ed. Boston: Harvard Business School Press.

- Khosrowpour, M. 1994. *Information Technology and Organizations: Challenges of New Technologies*. Harrisburg, PA: Idea Group Publishing.
- Kiesler, S., and T. Finholt. 1994. "The Mystery of RSI." In C. Huff and T. Finholt, eds., *Social Issues in Computing*. New York: McGraw-Hill.
- King, J.L., and K.L. Kraemer. 1997. "Computers and Communication Technologies: Impacts on the Organization of Enterprise and the Establishment and Maintenance of Civil Society." Paper presented at the Workshop on Economic and Social Impacts of Computers and Communications for the Computer and Telecommunications Advisory Board of the National Academy of Sciences, sponsored by the National Research Council and the National Science Foundation. Berkeley, CA, June 30-July 2.
- Kozol, J. 1991. *Savage Inequalities: Children in America's Schools*. New York: Crown Publishers.
- Kranzberg, M. 1989. "IT as Revolution." In T. Forester, ed., *Computers in the Human Context: Information Technology, Productivity, and People*. Cambridge, MA: MIT Press.
- Kulik, C.-L., and J.A. Kulik. 1991. "Effectiveness of Computer-Based Instruction: An Updated Analysis." *Computers in Human Behavior* 7: 75-94.
- Landauer, T.K. 1995. *The Trouble With Computers: Usefulness, Usability, and Productivity*. Cambridge, MA: MIT Press.
- Lesk, M. 1997. *Practical Digital Libraries: Books, Bytes, and Bucks*. San Francisco: Morgan Kaufman.
- Lichtenberg, F.R. 1995. "The Output Contributions of Computer Equipment and Personnel: A Firm-Level Analysis." *Economics of Innovation and New Technology* 3: 201-17.
- Link, A.N., and J.T. Scott. 1998. "Assessing the Infrastructural Needs of a Technology-Based Service Sector: A New Approach to Technology Policy Planning." *STI Review*. Forthcoming.
- Lyman, P., ed. 1996. "Books, Bricks, & Bytes." Special Symposium on the Changing Role of Libraries. *Daedalus* (Fall).
- Machlup, F. 1962. *The Production and Distribution of Knowledge in the United States*. Princeton: Princeton University Press.
- Malone, T., J. Yates, and R. Benjamin. 1987. "Electronic Markets and Electronic Hierarchies." *Communications of the ACM* 30, No. 6: 484-97.
- Marien, M. 1986. "125 Impacts of New Information Technologies." *Future Survey Annual 1986*. Bethesda, MD: World Future Society.
- Mark, J. 1982. "Measuring Productivity in Service Industries." *Monthly Labor Review* (June): 3-8.
- Martin, M. 1996. "When Info Worlds Collide." *Fortune* October 28: 130-33.
- McKinsey and Company. 1995. *Connecting K-12 Schools to the Information Superhighway*. Report prepared for the U.S. Advisory Council on the National Information Infrastructure. Available from <<<http://cavern.uark.edu/mckinsey/>>>.
- McNeil, B.J., and K. Nelson. 1990. "Meta-Analysis of Interactive Video Instruction: A Ten-Year Review of Achievement Effects." Technical research report. Document No. ED 321 761. Washington, DC: Educational Research Information Center (ERIC).
- Memmott, C. 1997. "History Takes on Net Proportions." *USA Today* (June 17): 13E.
- Moris, F. 1996. "Semiconductors: The Building Blocks of the Information Revolution." *Monthly Labor Review* (August): 6-18.
- Morisi, T.L. 1996. "Commercial Banking Transformed by Computer Technology." *Monthly Labor Review* (August): 30-36.
- Morrison, C., and E. Berndt. 1990. "Assessing the Productivity of Information Technology Equipment in the US Manufacturing Industries." Working Paper No. 3582 (January). Cambridge, MA: National Bureau of Economic Research.
- Morrison, I., and G. Schmid. 1994. *Future Tense: The Business Realities of the Next Ten Years*. New York: William Morrow and Co.
- National Center for Education Statistics (NCES). 1997. "Advanced Telecommunications in U.S. Public Elementary and Secondary Schools, Fall 1996." *Statistics in Brief* (February). NCES 97-944. Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement.
- National Information Infrastructure Advisory Council (NIIAC). 1995. *A Nation of Opportunity: A Final Report of the United States Advisory Council on the National Information Infrastructure*. Available from <<<http://www.ed.psu.edu/dept/ae-insys-wfed/insys/esd/Tech/Highway/nation.home.html>>>.
- National Research Council (NRC). 1993. *National Collaboratories: Applying Information Technology for Scientific Research*. Washington, DC: National Academy Press.
- . 1994a. *Information Technology in the Service Society*. Washington, DC: National Academy Press.
- . 1994b. *Realizing the Information Future: The Internet and Beyond*. Washington, DC: National Academy Press.
- . 1997. *For the Record: Protecting Electronic Health Information*. Washington, DC: National Academy Press.
- National Science Board (NSB). 1996. *Science & Engineering Indicators—1996*. NSB 96-21. Washington, DC: U.S. Government Printing Office.
- National Telecommunications and Information Administration (NTIA). 1995. *Falling Through the Net: A Survey of the "Have Nots" in Rural and Urban America*. Available from <<<http://www.ntia.doc.gov/ntiahome/fallingthru.html>>>; associated data tables available from <<<http://www.ntia.doc.gov/ntiahome/tables.htm>>>.
- Niemiec, R., and H.J. Walberg. 1987. "Comparative Effects of Computer-Assisted Instruction: A Synthesis of Reviews." *Journal of Educational Computing Research* 3: 19-37.
- Noyelle, T., ed. 1990. *Skills, Wages, and Productivity in the Service Sector*. Boulder, CO: Westview Press.
- NUA Ltd. 1997. NUA Internet Surveys. Available from <<<http://www.nua.ie>>>.

- Ogburn, W.F. 1964. *On Culture and Social Change: Selected Papers*. O.D. Duncan, ed. Chicago: University of Chicago Press.
- Oliner, S.D., and D. Sichel. 1994. "Computers and Output Growth Revisited: How Big Is the Puzzle?" *Brookings Papers on Economic Activity*. No. 2: 273-315.
- Oppenheimer, T. 1997. "The Computer Delusion." *The Atlantic Monthly* (July): 45-56.
- Pargh, A. 1997. "Competition Boots up in Home Computer Market." *USA Today* (June 17): 4E.
- President's Committee of Advisors on Science and Technology (PCAST), Panel on Educational Technology. 1997. *Report to the President on the Use of Technology to Strengthen K-12 Education in the United States*. Available from <<<http://www1.whitehouse.gov/WH/EOP/OSTP/NSTC/PCAST/k-12ed.html>>>.
- Pelgrum, W.J., R. Janssen, and T. Plomp, eds. 1993. *Schools, Teachers, Students, and Computers: A Cross-National Perspective*. International Association for the Evaluation of Educational Achievement. Available from <<<http://uttou2.to.utwente.nl/comped/fr2/contents.htm>>>.
- Perez, C. 1983. "Structural Change and Assimilation of New Technologies in the Economic and Social System." *Futures* 15, No. 5: 357-75.
- Porter, M., and V. Millar. 1985. "How Information Gives You Competitive Advantage." *Harvard Business Review* (July-August): 149-60.
- Regan, P. 1995. *Legislating Privacy*. Chapel Hill, NC: University of North Carolina Press.
- Rosenberg, R. 1997. *The Social Impact of Computers*. 2nd ed. San Diego: Academic Press.
- Rowe, S.A. 1994. "Management Involvement: A Key Element in Preventing Musculoskeletal Problems in Visual Display Unit Users in Australia." In C. Huff and T. Finholt, eds., *Social Issues in Computing*. New York: McGraw-Hill.
- Rubin, A. 1996. "Educational Technology: Support for Inquiry-Based Learning." In *Technology Infusion and School Change: Perspectives and Practices*. Model Schools Partnership Research Monograph. Cambridge, MA: TERC.
- Ryan, A. 1991. "Meta-Analysis of Achievement Effects of Microcomputer Applications in Elementary Schools." *Educational Administration Quarterly* 27, No. 2 (May): 161-84.
- Schofield, J.W. 1995. *Computers and Classroom Culture*. Cambridge, UK: Cambridge University Press.
- Science. 1996. "Computers in Biology." Special issue on the role of computers in biological research and knowledge accumulation. Vol. 273 (2 August): 585-607.
- Sichel, D. 1997. *The Computer Revolution: An Economic Perspective*. Washington, DC: Brookings Institution.
- Smith, J.H. 1994. *Managing Privacy: Information Technology and Corporate America*. Chapel Hill, NC: University of North Carolina Press.
- Solow, R. 1957. "Technological Change and the Aggregate Production Function." *Review of Economics and Statistics* 39 (August): 312-20.
- Stoll, C. 1995. *Silicon Snake Oil: Second Thoughts on the Information Highway*. New York: Doubleday.
- Tapscott, D. 1996. *The Digital Economy: Promise and Peril in the Age of Networked Intelligence*. New York: McGraw-Hill.
- Telecommute America. 1997. "News Release July 2, 1997." Available from <<<http://www.att.com/press/0767/970702.bsa.html#facts>>>.
- Thurow, L. 1987. "Economic Paradigms and Slow American Productivity Growth." *Eastern Economic Journal* 13: 333-43.
- Turkle, S. 1984. *The Second Self: Computers and the Human Spirit*. New York: Simon and Schuster.
- . 1995. *Life on the Screen: Identity in the Age of the Internet*. New York: Simon and Schuster.
- U.S. Bureau of the Census. 1993. Current Population Survey. October. Available from <<<http://www.census.gov/population/socdemo/computer/compusea.text>>>.
- . 1996. *Statistical Abstract of the United States 1996*. Washington, DC: U.S. Government Printing Office.
- U.S. Bureau of Economic Analysis (U.S. BEA). 1996. *Survey of Current Business* (August).
- . 1997. *Survey of Current Business* (May).
- U.S. Bureau of Labor Statistics (U.S. BLS). 1994. "Repetitive Tasks Loosen Some Workers' Grip on Safety and Health." *Issues* (August).
- . 1997a. Industry Productivity Index. Available from <<<http://stats.bls.gov/cgi-bin/dsrv>>>.
- . 1997b. *Monthly Labor Review* (November).
- U.S. Office of Technology Assessment (U.S. OTA). 1987. *The Electronic Supervisor: New Technology, New Tensions*. OTA-CIT-333. Washington, DC: U.S. Government Printing Office.
- . 1995. *Teachers and Technology: Making the Connection*. Washington, DC: U.S. Government Printing Office.
- U.S. Senate Committee on the Judiciary. 1995. *Cyberporn and Children: The Scope of the Problem, the State of the Technology, and the Need for Congressional Action*. Hearing before the Committee on the Judiciary, 104th Congress, 1st session, serial No. J-104-36.
- Utts, J. 1996. *Seeing Through Statistics*. Belmont, CA: Duxbury Press.
- Van Alstyne, M. 1997. "The State of Network Organization: A Survey in Three Frameworks." *Journal of Organizational Computing* 7, No. 3. Nos. 2 and 3: 88-151.
- Warnke, J. 1996. "Computer Manufacturing: Change and Competition." *Monthly Labor Review* (August): 18-30.
- Webster, F. 1997. "What Information Society?" In D.S. Alberts and D.S. Papp, eds., *The Information Age: An Anthology on Its Impact and Consequences*. Available from <<<http://www.ndu.edu/inss/books/Anthology1/part1.html>>>.
- Weill, P. 1992. "The Relationship Between Investment in Information Technology and Firm Performance: A Study of the Valve Manufacturing Sector." *Information Systems Research* 3, No. 4: 307-33.